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November 1966

A Recommended National Program In Weather Modification

A Report to the

Interdepartmental Committee for Atmospheric Sciences

by

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Washington, D.C.

Interdepartmental Committee
for
Atmospheric Sciences

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INTERDEPARTMENTAL COMMITTEE FOR ATMOSPHERIC SCIENCES
U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20230

ICAS Report No. 10a

November 7, 1966

MEMORANDUM FOR DR. DONALD F. HORNIG

Subject: Weather Modification Program

At its meeting of March 29, 1966 the Federal Council asked ICAS to prepare a report outlining "who is doing what in weather modification, the future plans of the agencies (particularly Commerce and Interior) and their interrelationships, and the considerations that should affect decisions on the division of responsibilities for research in weather modification."

Forwarded herewith is a Report prepared for ICAS by Dr. Homer E. Newell, the NASA member of ICAS. It has been thoroughly considered by our Committee and is endorsed as the ICAS response to the Council's request above.

J. Herbert Hollomon
Chairman

A Recommended National Program In Weather Modification

A Report to the

Interdepartmental Committee for Atmospheric Sciences

by

Homer E. Newell

Associate Administrator for Space Science and Applications
National Aeronautics & Space Administration
Washington, D.C.

1 October 1966

A RECOMMENDED NATIONAL PROGRAM IN WEATHER MODIFICATION

INTRODUCTION

The earth's weather has a profound influence on agriculture, forestry, water resources, industry, commerce, transportation, construction, field operations, commercial fishing, and many other human activities. Adverse effects of weather on man's activities and the earth's resources are extremely costly, amounting to billions of dollars per year, sometimes causing irreparable damage as when human lives are lost in severe storms. There is, therefore, great motivation to develop effective countermeasures against the destructive effects of weather, and, conversely, to enhance the beneficial aspects. The financial and other benefits to human welfare of being able to modify weather to augment water supplies, reduce lightning, suppress hail, mitigate tornados, and inhibit the full development of hurricanes would be very great.

Over the past twenty years experiments have been conducted on weather modification, particularly on the effects of seeding clouds with such materials as silver iodide crystals. The results are limited. Under suitable circumstances it has been possible to augment precipitation by ten to twenty percent, and to reduce the frequency of fire-producing lightning strokes. Effects on hail production have been noted, sometimes suppression and sometimes augmentation. These results probably would be of only passing interest were it not for the potential importance to mankind of further progress in this field. Perhaps the most significant result of the experiments to date has been to bring about a change in attitude from one of skepticism to one of cautious optimism. The limited success to date is encouraging, and underscores the

importance of pressing forward with the necessary research to understand the dynamics of weather systems that will have to be dealt with in any efforts at weather modification.

The gradually accumulating evidence of positive results from efforts at weather modification led the Committee on Atmospheric Sciences of the National Academy of Sciences, in November 1963,to appoint a Panel on Weather and Climate Modification "to undertake a deliberate and thoughtful review of the present status and activities in this field, and of its potential and limitations for the future."* The Panel made its report at the beginning of this calendar year (Ref. 1). The composition of the NAS Panel is given in App. I, together with a list of the Panel's recommendations. Elaboration and discussion of these recommendations may be found in Ref. 1.

On June 16, 1964, the Director of the National Science Foundation announced the appointment of a Special Commission on Weather Modification. To assist in its review of the field, the Commission activated seven subgroups to study the physical, biological, statistical, social, international, legal and legislative, and administration and funding aspects of weather and climate modification. The membership of the Commission and a list of the principal recommendations of the Commission are attached (App. II). Further elaboration and discussions of those recommendations may be found in the Commission's report and the report of the subgroups (Refs. 2 and 3).

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* Final Report of the Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences, National Academy of Sciences-National Research Council; "Weather and Climate Modification," Volume I-Summary and Recommendations, Publication No. 1350, 1966, pg vii

With the growing conviction of positive and potential results, a number of government agencies have been developing plans for research and ultimately operational programs in weather and climate modification. Some of these plans stem from the desire to use weather modification to meet specific mission responsibilities such as development of water resources, protection of crops, protection against forest fires, etc. Other plans stem from direct responsibility for furthering our understanding of weather and its uses. A summary report, "Present and Future Plans of Federal Agencies in Weather-Climate Modification," dated June 20, 1966, was prepared for the Interdepartmental Committee for Atmospheric Sciences (ICAS) by a Select Panel on Weather Modification (App. III). Whereas the ICAS Select Panel report reflected a desirable vigor in pressing forward in this important field, nevertheless, it raised a number of questions as to the soundness and adequacy of proposed plans, the validity of cost estimates, the availability of trained people to meet the schedules proposed, overlapping of research activities, duplication of proposed facilities, responsibility for coordination and reporting, and responsibility for regulation and control.

To discharge its responsibilities, ICAS must provide answers to these questions and make appropriate recommendations. To this end, the Chairman of ICAS, Dr. Herbert Hollomon, asked me to review the proposed plans and to submit recommendations that might be adopted by ICAS for a report to Dr. Donald F. Hornig, Director of the Office of Science and Technology, Executive Office of the President.

TERMS OF REFERENCE FOR THIS STUDY

The terms of reference for this study are set forth in the memorandum from Dr. Hollomon to me (App. IV), specifically requesting me to formulate a National Weather

Modification Program along the lines delineated in the report of the ICAS Select Panel on Weather Modification.

APPROACH

I have taken the ICAS Select Panel Report (App. III) as my starting point, and have used the NAS Panel and NSF Special Commission Reports (Refs. 1, 2, 3) as sources of expert thinking on the subject. In order to penetrate in sufficient depth into the problems involved, I put together a panel* of NASA experts, the constitution of which is given in App. V. We met a number of times with representatives from the Department of Agriculture, the Environmental Science Services Administration (ESSA), the Interior Department's Bureau of Reclamation, and the National Science Foundation (NSF), to hear briefings on program plans and budgets, to discuss proposed schedules, staffing, facility construction, and operations, and to review in some detail the validity of cost estimates. We received from these agencies a considerable volume of supporting documentation. Appendix V also includes a chronology of Panel meetings, and a list of material reviewed by the Panel.

I elected to concentrate attention on the above four agencies, since their programs, as set forth in the ICAS Select Panel Report, project to over 98% of the total national weather modification activity in 1970. Because the programs of the Department of Defense, the Federal Aviation Agency, and the National Aeronautics and Space Administration were such a small part of the total, they were not reviewed in detail.

In assessing the validity of cost estimates, I sought to determine realistic and reasonable orders of magnitude. Particular attention was paid to assessing

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* Henceforth the NASA Panel will be referred to simply as "the Panel."

the realism of the estimates of manpower resources and availability, and their impact on possible rates of growth. I also sought to separate those areas meriting early attention from those of a longer range nature that could be approached more slowly.

The observations and recommendations contained in the following sections are based on the Panel reviews and deliberations. It should be emphasized that the recommendations deal with the major problems, on the assumption that if the major problems are resolved the remaining pieces can be fitted into place.

RECOMMENDED PRINCIPLES

Certain principles were developed which underlie the program recommendations. It is recommended that these principles be accepted in the development of the National Weather Modification Program. It is intended that the principles apply to all agencies involved in weather modification activities, and not just to those whose programs are discussed in detail in this report. The principles are:

1. There is sufficient potential payoff indicated by the results of past research to justify continuing basic and applied research in the area of weather modification.

2. The potential dollar savings in lessening the destructive effects of weather, and the potential gains in enhancing the beneficial effects, are so great that expenditures of appreciable dollars on weather modification research and application can be justified.

3. There is a need for a single agency to assume responsibility for taking the lead in developing a well-rounded national program of research on

weather modification, properly related to weather observation and weather research. (Such a lead agency would, however, not have authority to control the content of other agency programs.)

4. It is of value and desirable to maintain multiple agency approach to weather modification research and application, with independent funding for the different agencies.

5. An agency that has a major mission responsibility requiring weather modification, for example, augmenting water resources or minimizing forest fires, must be an active participant in the total weather modification program, but with the agency's mission focusing and broadly defining its activity.

6. To achieve the most effective application of weather modification to its mission objectives, a mission agency must understand the basic problems, and hence must be involved significantly in related research. Thus, while the agency's mission should focus its participation in the weather modification program, the mission should not too narrowly confine that participation.

7. The various agencies participating in the weather modification program must support each other with their experience and capabilities. In areas where several federal agencies have needs for laboratories and large facilities, joint use should be made of such facilities. Similarly, existing competence should, in general, be used by other agencies rather than duplicated. In particular, the central agency having responsibility for focusing the national program into a properly balanced and integrated total must not attempt to

do everything itself for everybody; rather, it should build judiciously upon the activities, capabilities, and mission responsibilities of the various participating agencies.

8. A formal procedure must be developed to achieve continuing visibility and coordination of the total weather modification program.

9. There must be regulation and control of weather modification activities, especially as those activities increase in magnitude and frequency and become international in scope. This is required especially to provide a mechanism for protection against harmful consequences of weather modification activity but also to permit valid experimentation.

OBSERVATIONS

I found that the budget figures in the ICAS Select Panel Report did not reflect the current status of agency program analysis and planning. Indicated rates of growth in the Select Panel Report were unrealistically high, in some cases by a factor of two or more.

As well as I could determine, the various agencies are counting in large measure on using the same people at various contractors and universities to help carry out the planned programs. ESSA appears to have the kind and quantities of people required to mount a vigorous program in weather modification research, but the ability to build up program activity at anything like the proposed rates would depend upon whether these people can actually be reassigned from their present duties. In general there was a large disparity between projected manpower availabilities and requirements. This serves to emphasize that proposed rates of program growth are indeed too high, and also that a vigorous effort should be made to increase the total national competence in the weather modification field.

There are a few areas of sufficient immediate promise to warrant moving ahead on experimental operational programs. One is the seeding of orographic clouds in western areas to augment water precipitation for increasing water supply. Another is the seeding of dry, shallow storms in the Rocky Mountain regions for suppression of the kind of lightning that causes forest fires. In other areas it appears too early at the present time to undertake operational applications of weather modification. What is needed at the present time and for the immediate future is a program of research, including some field programs, directed toward understanding the physics and dynamics of weather systems to provide a scientific basis for further experimentation in weather modification.

In general, the proposed program content for all four agencies appears sound, being based on assessments of potential practical returns, or on a recognition of the need for research. Except for questions of undesirable duplication, my criticism lies not in the subject content of proposed programs, but rather in the areas of program phasing, proposed rates of growth, and the validity of dollar estimates.

PROGRAM THRUST, ASSESSMENT, AND RECOMMENDATIONS

Major Thrust of Program

It is recommended that the major thrust of the National Program in Weather Modification for the immediate future be in the direction of understanding the physics and dynamics of weather systems to provide a sound basis for experimentation in and application of weather modification. This will require programs of field experimentation to extend and apply the results of laboratory and theoretical research.

Budget

1. It is recommended that the agencies participating in the weather modification program give early attention to the development of valid budget figures, with particular attention to realistic rates of growth, and valid estimates of manpower availability.

2. While I recommend a vigorous National Program of Weather Modification, I feel that the size projected for FY 1970, including major facilities, might reasonably be little more than half of that given in the ICAS Select Panel Report.

Because the various agencies were unable to provide firm budget estimates, I was in no position to develop a definitive budget. I have, however, plotted some trends in Fig. 2 of App. VI which quantitate in a rough way my recommendations relative to the specific agency programs. The numbers used were arrived at from discussions with the agencies and among ourselves. The numbers may well have to be changed after the agencies have completed their analyses of actual requirements;

in the meantime, these may be taken as indicating my judgment as to reasonable orders of magnitude.

Department of Agriculture Program

I believe that a weather modification program of about $600K in FY 1967 growing to $7M in FY 1970 is justifiable. About half of the FY 1970 figure is for facilities, including purchase and operation of small aircraft and a much needed research laboratory. If research yet to be done shows a mission-oriented program in hail suppression to be warranted, the FY 1970 figure could be larger.

The Department of Agriculture program, projected through FY 1970, can be considered in terms of two major categories:

1. Direct modification of weather
2. Ecological and supporting research

These relate in the main to the suppression of specific harmful effects of weather phenomena, and a study of the effects of weather modification upon farm and forest crops and on land management in general.

The direct weather modification portion of the program includes primarily an expanded lightning suppression effort and a new effort directed toward hail suppression, the Department states: "Project Skyfire of the U.S. Forest Service is performing an active research program aimed at suppression of lightning which causes some 10,000 forest fires annually in the United States. A field experiment is testing the effects of very heavy seeding with silver iodide on lightning storms. The results to date show a 32 percent reduction in cloud-to-ground lightning from seeded storms. A specially instrumented field area utilizing three radars and a network of lightning sensor stations is used for the

cloud seeding experiments and for studies of lightning characteristics. The type of lightning discharge most likely to ignite forest fires has been identified. High output airborne and ground based silver iodide generators have been developed. Utilizing data from the experimental area and a network of lightning survey stations, physical and mathematical models of mountain thunderstorms are being developed."*

Project Skyfire is providing the basis for achieving a significant reduction in lightning damage in the forest areas of the western United States, which is of appreciable benefit to the country. The objectives of Skyfire clearly fall within the mission responsibilities of the U.S. Forest Service, which should continue to be responsible for the project.

The present program has been underway for over ten years. From the data presented to the Panel, it appears that this effort has been underfunded in relation to its potential value to the agency's mission, and to the Nation. I recommend, and regard as minimal, the following effort proposed by Agriculture:

1. Expanded lightning investigations at the Missoula Experimental site and at the Northern Forest Fire Laboratory.

2. Performance of larger scale seeding experiments in two well instrumented experimental areas in the National Forests of the Northern Rockies. A capability should be developed, by strengthening research resources already available, to operate these experimental areas either separately or simultaneously.

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* United States Department of Agriculture, Summary of Weather Modification Research Program presented on June 28, 1966.

3. The concentration of research on determining the seeding effects on lightning discharges having long continued current portions. Evidence now available indicates that these hybrid discharges are of major importance in igniting forest fuels.

4. Continued research in the development of high output silver iodide smoke generators and in the development of seeding systems for use in forest protection.

5. Continued research in the development of a lightning fire intelligence system including storm tracking, discharge measurements, and lightning risk evaluation in the forest fire danger rating program.

Most of the Agriculture budget is to support the above program, and includes all necessary facilities such as observational networks, operation and acquisition of research aircraft, cloud seeding equipment, radar, and a special laboratory for lightning studies. These facilities and the increased efforts they support represent, in my opinion, realistic growth.

There is at the present no substantial Department of Agriculture effort in hail suppression. The Department states: "The Department of Agriculture research program in hail suppression is in an embryo stage. The main activity is preliminary planning of a long range research program."*

The Department of Agriculture's mission responsibilities for crop protection were well documented and defined to the Panel, and are the basis for an active

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*United States Department of Agriculture, Summary of Weather Modification Research Program presented on June 28, 1966.

interest in hail suppression. No scientific details were submitted, however, to justify undertaking a large-scale program at this time. Scientific results to date are inadequate for defining a valid program to apply hail suppression techniques to such applications as crop protection.

I recommend against the expansion of Agriculture's hail suppression efforts beyond a modest effort for the time being. I recommend that the Environmental Science Services Administration, in close cooperation with the Department of Agriculture, take the lead in the development and conduct of a program to understand the basic physics of hail-producing storms, and of hail-suppression mechanisms. I recommend that, as the necessary scientific rationale is developed, the Department of Agriculture take the lead in conducting large-scale field experiments in hail suppression, particularly in the western plains area where hail damage to agriculture is most severe. Should this become achievable in the 1970 time period, the total Department of Agriculture weather modification budget for FY 1970 would have to be larger than the $7M indicated earlier.

The ecological and supporting research portion of the program includes three areas: biological responses to weather modification, boundary-layer energy exchange, and remote sensing in support of weather modification. At present, there is little work under way in the first area, and only modest, early efforts exist in the last two.

I feel that Agriculture's experience and in-house capabilities in such areas as ecology, boundary-layer energy exchange, and basic research in support of their excellent lightning suppression program require augmentation. These efforts are pertinent to a program of weather modification research and application, and are otherwise part of the Agriculture mission. In some regards, however, I do have concern. Field observations related to changes

in species brought about through weather modification, for example, involve considerable uncertainties relative to the specific results of weather modification. It is very important, therefore, to establish early the necessary baseline data for later comparisons and analyses. Similarly, a program in boundary layer effects generated through weather modification must deal with difficulties of establishing firmly a true cause-and-effect relationship.

I conclude that the budget submission by Agriculture for research in the ecological and supporting research portions of the program is in excess of the present capability.

Nevertheless, I feel that growth in these fundamental areas is desirable and should be supported.

Department of Interior Program

I recommend a Department of Interior budget for weather modification activities of about $3M in FY 1967 growing to about $35M in FY 1970, including needed facilities and operation. The main thrust of Interior's program is in the area of precipitation augmentation. The Department of Interior has been assigned national water resource management responsibilities, and thus an effort in the exploitation and utilization of the water resource is clearly an Interior mission and is in the national interest.

The singular objective of Interior's Atmospheric Water Resources Program has been to ascertain the technical and economic feasibility of increasing the water supply for Bureau of Reclamation projects through weather modification. Research results to date show sufficient promise that the program has been reoriented to reflect the eventual goal of the "effective,

beneficial utilization of the nation's atmospheric water resources."*

The program to date has included, appropriately, cloud-seeding efforts, research involving the acquisition of field data in all the experimental areas, and climatology.

Interior's program has concentrated on a number of field experiments in the western states. A program at the University of Wyoming devoted to the study of cap clouds has produced amounts of water which appear to offer promise of economic significance. Interior's Basin program ranges from theoretical studies of cloud physics to actual modification operations, and includes the development of instrumentation and data acquisition systems.

The Southern Sierra program has studied the effectiveness of cloud seeding in that specialized area. The Pacific Northwest program has included experiments on shifting precipitation from areas of surplus to areas of deficit.

In Washington and Oregon the windward slopes of coastal mountains receive large amounts of precipitation, the run-off of which returns to the ocean unused. Farther inland, there are areas where the precipitation is less than one tenth as great. If it were possible to shift some of the lost precipitation, the economic benefit would be great.

The research program submitted by Interior to ICAS reflects quite well all areas of study that will be required to support proposed intensive field experiments

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*Plans for the Department of Interior's Atmospheric Water Resources Program, presented to ICAS on May 13, 1966.

in precipitation augmentation such as those mentioned above. I conclude that the program is soundly based, is being competently carried out, is of benefit to the country, and should be continued. I feel that the proposed rates of growth exceed Interior's in-house and potential contractor capability and I recommend the lower rate of growth for this research area corresponding to the budget figures given above.

The supporting budget material submitted to the Panel discussed the establishment of field laboratories which would include the following necessary facilities: radar and rawinsonde installations, balloon inflation shelters, repair shops, airports, temporary housing, etc. I feel that the establishment of an extensive network of such field stations is appropriate technically and eventually should be accomplished within the Department of Interior's mission. I estimate that not more than ten field sites are consistent with the apparent potentialities of the Department of Interior through the FY 1970 time period. The cost per field site as deduced from the material provided by Interior is approximately 2½ million dollars including such equipment items as weather radar, rawinsondes, telemetry sets, tracer dispensers, and a total of about eight twin engine aircraft for the ten field sites. This equipment is representative of the proposed site implementation set forth in the material supplied by Interior.

I recommend that Interior collaborate with ESSA in accomplishing Interior's mission of augmenting precipitation in the eastern or northeastern sector of the country. I believe that there are significant advantages to Interior's developing a firm, clearly defined agreement with ESSA to accomplish this collaborative effort. Such an arrangement would spread the base of the government's experience in this field. It would permit ESSA to integrate the precipitation augmentation activity with a broader program of research on the physics and

dynamics of weather modification and with weather research in general. Also, it would provide Interior with valuable assistance in its important water resources program. If such a collaboration with ESSA is arranged, ESSA's assistance may permit acceleration of the precipitation augmentation program, which in turn would require earlier increases in the Interior budget than are indicated in the curve of App. VI.

The collaboration recommended above is one example of how two agencies may profitably work together to achieve their respective goals. It may be expected that many such opportunities will arise in the weather modification program, and full advantage should be taken of those opportunities. The development and operation of a large-scale weather simulation facility will benefit from multiagency collaboration in its design and use. Although I recommend below that ESSA be the prime mover in the area of severe storm modification, it is recognized that Interior and Agriculture have an ultimate interest here, and one can foresee the possibility of collaborative efforts among ESSA, Interior, and Agriculture.

Like the Department of Agriculture, the Department of Interior has an interest in and concern with the ecological effects of weather modification. In planning for programs in atmospheric water resources, the Department is including provision for appropriate studies in this area.

ESSA Program

I recommend a weather modification budget for ESSA of about $1.5M in FY 1967, rising to about $25M in FY 1970. I support the program content, but question the proposed rate of growth to $20M in FY 1968. While ESSA demonstrated the necessary diversity of in-house talent, I am unable to judge whether ESSA is able to reassign all the needed personnel from other areas to the weather modification effort.

The proposed ESSA program is a broad research and development effort of significant magnitude and content. It covers the many areas that must be understood to attack and solve the problem of attaining beneficial weather control. The following technical areas, from a list provided by ESSA, illustrate the breadth of the proposed effort: cloud physics; atmospheric electricity; statistical design and evaluation; hurricane structure and modification; severe local storm structure; atmospheric contamination; inadvertent modification; computer modeling; global cloud analysis, primarily satellite work; drought and climatic variations; atmosphere radiation and heat balance; sea/air interaction; transport and diffusion plume tracing; specialized instrument development; hydrometeorology; socio-economics; and ecology.

I believe that a broad research and development effort of the general content of the proposed ESSA program is essential to a significant national weather modification effort. I recommend that ESSA have the responsibility for the research and development that is essential to a viable national weather modification program, supplementing and integrating the research programs of the mission-oriented agencies. But, I recommend that ESSA not duplicate the programs of the mission-oriented agencies discussed above, and the basic research programs of NSF discussed below. I strongly support the ESSA mission responsibility in areas such as severe storm suppression, hurricane modification, and large-scale long-range atmospheric modeling.

The following areas are considered essential for establishing the broad base of research necessary for the national weather modification effort. The descriptions given below were extracted from the material provided by ESSA. The recommended funding permits inclusion of these activities in the ESSA program.

1. Modification of Winter Lake Storms: These storms form in early winter when shallow continental cold air blows across the unfrozen lakes, picking up moisture from the warm water surface. The local character of the storm would permit over-seeding and redistribution of the precipitation.

2. Modification of Colloidal Stability: An attempt would be made to seed tropical maritime clouds with condensation nuclei in order to increase their colloidal stability and to prevent rain. This activity may enter a semi-operational state during FY 1972.

3. AgI Diffusion: This project supplements the research under item 1 above. It is believed that the vertical diffusion of AgI can be studied in the winter in the Great Lakes Region during presence of extended supercooled cloud layers. AgI will be generated in great concentrations at the surface. The analysis of its effect on the cloud deck will be done by radar.

4. Cumulus Dynamics: This is part of Project Storm Fury. It involves the continued study of cumulus dynamics by means of the release of heat of fusion through seeding with pyrotechnics. A two-year cycle of randomized field experimentation is foreseen in the Barbados Island area, which permits study of both maritime and continental clouds.

5. Hail Suppression: Several approaches are contemplated: (a) a field project to study hailstone structure to determine where in the cloud the hailstone originated, (b) airborne studies of hailstorms to assess the relative significance of mothercloud and anvil in the hail process, and (c) radar studies to analyze further the "anatomy" of the hailstorm.

Areas of activity will be Norman, Oklahoma; Boulder, Colorado; and Flagstaff, Arizona.

6. Inadvertent Modification: Inadvertent modification of the weather occurs because of pollution of the atmosphere by artificial gaseous and particulate constituents, and changes in surface character and albedo due to agriculture and construction. The effects of air pollution become apparent in three areas: atmospheric chemistry, optics, and electricity, all of which are studied in this program.

(a) Benchmark Program: The concentration of atmospheric constituents, naturally and artificially generated, will be measured at various locations. The Mauna Loa Observatory and the Boulder stations will take part in the full program. Other stations may be selected in the Eastern U.S. and in the northern and southern hemispheres. The program will begin by monitoring O_3 and CO_2 contents. The first phase will concern itself with the development of a CO_2 monitoring method. Eventually, the concentrations of sulphates, nitrates, chlorides, and biological contaminants will also be monitored.

(b) Albedo, turbidity, radiation, aerosols: It is planned to start on a systematic research program to study these parameters.

(c) Atmospheric electric parameters: It is planned to study the electrical parameters (potential gradient, conductivity, air-earth current) of the undisturbed weather using radiosondes already developed. These parameters may prove to be a powerful tool for monitoring natural and artificial air pollution.

7. Study of Rain and Snow Precipitation: The importance of the concentration of precipitation particles for effective rainout must be studied. It is planned to conduct field experiments using radar, and raindrop spectrometers, and to develop theoretical precipitation models.

Research under this project will probably require many years.

8. Laboratory Studies: A number of in-house studies are planned:

(a) Construction of a fluid model for the study of influx characteristics into tornadic storms.

(b) Nucleation studies: Studies are planned to learn more about the action of silver iodide as a freezing or as a sublimation nucleus, and about its aging under irradiation by the sun. In addition to these studies, various other nucleating agents, such as lead oxide, will be investigated. This may lead to the discovery of less expensive materials with a dispersability equivalent to AgI, and usable in pyrotechnic dispensers.

9. Water Budget of Storms: Little is known of the water budget of extratropical storms. Analyses by Bradbury, Elliott, and Atlas, and by Wexler indicate that water storage occurs in such storms and that therefore chances of rain augmentation exist. Systematic investigations however are missing. The same is true of convective storms. Only for the case of air mass thunderstorms does an analysis exist (by Braham), while the water budget of hailstorms or tornados is unknown. One analysis of the influx of air into these storms gave values of more than 100 cubic kilometers in one minute.

Plans call for a diversified approach. In the initial phase the total precipitable water will be studied using a network of existing U.S. weather instruments. This study will be designed to furnish the influx of vapor across the shores of the Gulf of Mexico for certain weather situations, or from the Gulf of California, for instance, for the short period of the summer monsoon which is so important to Arizona. The second phase calls for a meteorologic analytic study of the water budget of storms, supplemented by aircraft and radiosonde network data collection.

10. Fair Weather Cumulus Studies: There has been considerable progress in computer modeling of cumulus convection. Further progress requires the input of data measured inside cumulus clouds. It is intended to initiate a program of in-cloud measurements using novel instrumentation. Temperature will be measured using remote IR techniques from the penetrating aircraft; other parameters, e.g. updraft and liquid content, will be measured as instrumentation is developed.

11. Atmospheric Chemistry: This project is geared to the application of chemical analysis methods to atmospheric physics. It is intended to measure, record, and analyze the chemical constituents of clouds, rain, and other precipitation. Ion conductivity, pH value, and ion identity, are some of the parameters which will be recorded at mountain stations as well as on aircraft.

12. Instrument Development: Instruments must be developed to perform over the whole range of atmospheric parameters for use in aircraft as well as on the ground.

Other equally important areas of investigation will arise as the entire program gets moving. I believe that projects in the above areas of basic research can now be implemented and are within the technical capability of ESSA.

An important recommendation of the National Academy of Sciences was "the early establishment of several carefully designed, randomized, seeding experiments, planned in such a way as to permit assessment of the seedability of a variety of storm types."* One of these should be in the eastern sector of the U.S. As noted above under the

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*Final Report of the Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences, National Academy of Sciences-National Research Council; "Weather and Climate Modification, Problems and Prospects," Volume I- Summary and Recommendations, Publication No. 1350, 1966, pg 23.

section on Interior, I propose that Interior collaborate with ESSA on a large-scale field program in precipitation augmentation in the eastern or northeastern section in keeping with the concept that the Department of Interior has mission responsibility in water resources enhancement while ESSA should conduct a broad program of exploratory research into the potentials and scientific bases for weather modification. A very important reason that ESSA undertake this work with Interior under a memorandum of understanding is so that ESSA may integrate this activity with their broader program of research on the physics and dynamics of weather.

The ESSA ongoing efforts in severe storms and hurricane research, and the development and use of the Norman, Oklahoma, facility, should be augmented at about the rate proposed by ESSA.

The National Severe Storms Laboratory (NSSL) has a comprehensive observational facility used to define better the conditions which spawn severe storms, the local circulations which are the storm, and the associated budgets of water substance and energy. During the observational period April-June 1966, this included calibrated Doppler and conventional radars, networks of 56 surface weather stations, 175 raingages, 10 radiosonde stations provided by the U. S. Air Force and the U. S. Army, and a 1600-foot instrumented television tower, cloud cameras, and several instrumented aircraft of ESSA and USAF. A lightning locating system is under development also, in order that the electrical energy of storms can be correlated with tornado development and the distribution of precipitation revealed by radar.

ESSA feels that a more accurate description of the storms can be obtained by interpretation of the observations in light of constraining principles of mass continuity and energy conservation or conversion.

In addition to theoretical studies and data analysis, some important present and planned efforts are:

1. Round-the-clock radar surveillance and data recording. This should provide means for determining associations among severe storm occurrences and topography, time of day, season, and synoptic meteorological parameters, and will provide a body of control data for the better evaluation of attempts by NSSL and other agencies to modify Oklahoma storms.

2. Continued development of computer programs for processing the voluminous radar and mesonetwork data.

3. Installation of additional mesonetwork surface stations between existing ones now located 10 to 15 miles apart. Additional stations are needed to record adequately the scales of motion characteristic of severe storms.

4. Construction of a 10cm-Doppler radar for improved velocity measuring capability at longer range.

5. Development of improved means for direct digital recording and processing of conventional and Doppler radar data.

Scientists at the National Hurricane Research Laboratory, Miami, Florida, and cooperating groups are studying the hurricane and its environment, and other tropical circulations that either may become a hurricane or affect the development of one. The following discussion furnished by ESSA gives the rationale for the hurricane research program.

We can now describe the structure of a mature hurricane in great detail and can even estimate probable variations in the structure with time in the same hurricane or between hurricanes. Our knowledge of the structure of developing and dissipating tropical cyclones is less complete, but even in these cases many data have been collected and analyzed.

Great advances have been made in recent years in developing mathematical models of hurricanes. The most advanced of these models is now being used for partially evaluating simple modification hypotheses.

In spite of all the progress that has been made in hurricane research in recent years, much needs to be done before we can (1) gain an adequate understanding of many details of the energy processes in hurricanes, (2) satisfactorily explain or predict the formation and intensification of tropical cyclones, or (3) develop realistic and accurate dynamical numerical models of hurricanes.

When we can simulate a hurricane with a good numerical model we will have accomplished a major breakthrough in the efforts to find a technique for modifying these storms. Two of the major deficiencies in the hurricane models currently being tested are the mathematical formulations both for the friction layer and for the transfer of energy between the earth and the atmosphere and through the lower layers of the atmosphere. Until our knowledge and understanding of these processes is greatly improved, it is doubtful if we will be able to simulate a hurricane with a truly satisfactory numerical model.

We would have a better chance of developing good mathematical formulations for the hurricane friction layer and for the transfer of energy if we had the right kind of data for testing the formulations that are proposed. We need to know the rate and means of the transfer of momentum, sensible heat, and water vapor with its latent heat. We should be able to determine these things if we had good measurements of the vertical and horizontal wind components, temperature, and humidity at a number of levels from sea level up through the first few thousand feet of atmosphere. These data are needed for the turbulent as well as the larger scales of motion.

Efforts to acquire a better understanding of the genesis process, and to develop techniques for predicting hurricane formation and further intensification are likewise handicapped by lack of data. This is due to the fact that the favored genesis areas are outside the conventional data networks. Some of the needed data can be obtained by research aircraft. Collection of these data could be greatly accelerated, however, with more aircraft of greater range. The improved weather satellites are already helping this data collection effort and the synchronous satellite should be of great assistance. It is hoped that the tropical experiment and the improved data collection efforts proposed for the World Weather Watch will also be useful.

Along with the increased efforts at specialized collection, there should be more theoretical investigations. These should include not only the study of the hurricane but also the other circulations in the tropics. It is unlikely that we will ever fully understand the hurricane until we have a better understanding of its environment.

As a note of caution, I feel a point should be made on the complexity of the proposed research. As illustrated by current progress with Project Storm Fury, the probability of acquiring a hurricane for modification purposes at this time seems to be about three storms every two years. Indeed, current efforts have yet to acquire the first such storm well into the second year of operation. For hurricane studies and possible modification, expensive facilities such as flight research aircraft are required on a seasonal basis, with the understanding that natural variance in the desired weather pattern prohibits a prediction of how long such research must be continued before meaningful results can be expected.

I recommend that the proposed effort by ESSA in the areas of severe storm and hurricane research be supported and pursued vigorously.

NSF Program

I recommend an increase in the National Science Foundation (NSF) weather modification budget to about $5M in FY 1967, growing to $20M in FY 1970. The FY 1970 figure includes $10M for the construction of a large-scale simulation facility for basic research in cloud physics to be erected and operated by the National Center for Atmospheric Research (NCAR). If planning for the facility moves rapidly, some of the $10M might be needed earlier than FY 1970.

The National Science Foundation proposes to increase the support of basic and closely associated applied research which is appropriate and fundamental to any program of weather modification. The NSF program should be directed toward three important objectives: (1) the establishment of a sound scientific foundation for an intensified program of weather modification, (2) the substantial involvement of universities in this area of research, and (3) the production of substantial numbers of new highly trained people for this work. NSF does not plan to and "will not duplicate

research performed by mission agencies, but will support research in those multi-discipline areas which will supplement or extend other weather modification research already underway and will develop the nation's resources of knowledge and manpower in new and imaginative areas."*

The NSF research program to be conducted primarily at universities and NCAR will include the following areas of research:

1. Cloud Dynamics: Basic studies will be continued on the motions of clouds, and the effects upon their growth or decay produced by the release or absorption of the heat of condensation and heat of fusion which may be produced or induced by natural or artificial stimulus. These studies will be carried on through actual observations of clouds in their natural environment, in simulation chambers in the laboratory, or by theoretical models using high speed computers.

2. Ice Formation in Clouds: The role of the formation of ice in clouds in producing raindrop formation will be intensively studied. The mechanism whereby atmospheric nuclei, both natural and artificial, become effective in freezing supercooled droplets will be further studied, and the importance of this process in competition with coalescence and sublimation will be assessed. The means whereby ice crystals grow to hailstone size in severe storms will also receive attention, especially as it relates to possible control mechanisms.

3. Coalescence: The process whereby cloud particles combine to form raindrops in warm clouds will be studied. The relationship of this process to the quantity and effectiveness of natural or artificially introduced condensation nuclei will be observed using airborne

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* "Critique by Presenter" enclosure to June 28, 1966, NSF letter to Homer E. Newell signed by P.H. Wyckoff, Program Director for Weather Modification.

instrumentation in the field, in cloud chambers or cloud tunnels in the laboratory, or by theoretical considerations using mathematical models. The contribution of electrical forces to coalescence processes will also be studied.

4. Cloud Electrification: The mechanism of charge generation in clouds will be studied in natural clouds containing either supercooled water or ice. The effect of freezing of cloud droplets on the orientation and location of charge centers will be observed. The effect of charge transfer upon the structure and dynamics of the cloud before and after lightning stroke formation will be assessed.

5. Computer Analysis: Advances will be made in computer technology in the universities and at NCAR to permit more accurate mathematical modeling of the large scale motions of the earth's atmosphere leading to the evaluation of possible practical techniques for a more desirable distribution of moisture bearing air masses over drought areas or regions of precipitation excess. The accompanying long-term changes in climatic structure will also be carefully considered.

6. Socio-Economic, Legal, and Ecological Consequences of Weather and Climate Modification: The recommendations of the NSF Special Commission on Weather Modification to assess the social, economic, legal and ecological effect of weather modification upon society will be the object of intensive research in order to isolate and evaluate those critical factors which will produce the most significant impact upon society due to the successful application of weather and climate modification techniques by mission agencies.

The university research in weather modification to be supported by NSF provides the primary mechanism for producing the numbers of trained scientists that the total program will require. Excessive funding from NSF, however, would

monopolize a major source of qualified personnel that the other agency programs must rely on. I recommend, therefore, a funding level for NSF sufficient to support about half of what NSF estimates to be the total capacity of the academic community in the area of weather modification in addition to activities at NCAR. This level of support would clearly permit NSF to fund programs adequately that are now being "stretched" and would provide the stimulus needed to better satisfy the NSF program stated above. I recommend further, because of the fundamental importance of achieving the three objectives as early as possible, that the NSF budget be increased immediately to the levels suggested above.

Capital Facilities

I support, in general, the agency proposals for extensive capital facilities which are necessary to carry out research and development as well as operational missions. Such facilities include aircraft, extensive field installations consisting of meteorological sensor networks and data analysis facilities, large laboratory installations (cloud chambers, etc.), and high-speed, large-capacity digital computers for modeling of atmospheric processes. Allocation of facilities should be based on the following principles:

1. If a major facility serves a special mission-oriented purpose and full-time use can be justified for that purpose, the facility should be established and operated by the specific element of the agency charged with that mission.

For example: Small aircraft and field sites fully used by the Department of Agriculture in their lightning suppression mission should be established and operated by the Department of Agriculture as part of that mission. In general,

radiosonde balloons, small-scale laboratory and computing facilities, and individual aircraft should be contained in the specific missions where they are needed.

These considerations are reflected in my conclusions and recommendations set forth in the preceding sections.

2. If a facility is not used for one specific mission, but can be justified on a full-time use basis for general weather modification purposes by one single agency, that agency should establish and operate the facility.

For example: I support the establishment and operation of appropriate aircraft and facilities by the Department of Interior to execute their precipitation augmentation mission. I also support the ultimate establishment by ESSA of a general purpose fleet of aircraft for use in that agency's diversified R&D and mission programs.

3. If a facility is for general-purpose use, but is so extensive that full-time use cannot be justified by a single agency, then the use of the facility will have to be shared by the agencies and the responsibility for its establishment and operation should be assigned on a case-by-case basis.

Specifically, the major field sites, large cloud chambers, large-scale computers, and large-scale integrated flying laboratories fall into this category.

In assigning responsibility for these facilities consideration also should be given to their use by individual agencies for purposes other than weather modification.

I recommend that ESSA's proposed program for field facilities, in addition to the Norman, Oklahoma facility, be conducted with due regard for the mission needs of the Department of Interior. Specifically, the first step in this expansion should be a general purpose field facility in the Northeastern United States. ESSA should establish and operate the site not only for ESSA's research, but also in collaboration with the Department of the Interior, and the facility should be shared between at least these two agencies.

The development of an understanding of the basic physics of cloud formation, dynamics, and dissipation is of prime importance in determining the mechanisms that can be used to modify clouds and cloud systems. As a weather simulation facility, the very large cloud chamber holds promise to be a powerful tool for such investigations. At the same time, prudence dictates that some experience be obtained with one such chamber before any consideration is given to the construction of others. Because such a facility bears a very strong relationship to university research programs and the training of research talent, I recommend that such a facility be established and operated by the National Center for Atmospheric Research under NSF sponsorship. On the other hand, because of the importance to other agencies of the research to be done with the cloud chamber, I recommend that NSF associate the other agencies with NSF in the planning and design of the chamber, and in its use after construction.

The present-day operation in modeling techniques and numerical forecasting procedures indicates that a large-scale, yet to be developed, computer may well be required. The planning of industry in regard to large computers needs to be known. Also, the basic research of the programs recommended earlier in this report should clarify the role of such computers, and may indeed remove some of the need for them. Here again, however, I recommend a careful planning phase. I also recommend that ESSA should establish and operate large-scale digital computers for the purpose of applying atmospheric circulation models to weather modification. It is expected that establishment and operation of these computing facilities could be funded at least partially by, and shared with, other programs within ESSA.

While I feel that a large mobile flight facility, for both weather and weather modification research is important to the long range development of these fields, I am unable to determine at this time what would be a reasonable program for the establishment of such a facility. I believe it would be wise to follow a step-by-step process of arriving at an optimum large-scale flight facility, in which the development and use by individual agencies of their own necessary smaller-scale flight facilities would be valuable learning steps. I feel that the latter should not be neglected in the haste to bring a large-scale facility into being. I recommend that work toward the large-scale flight facility remain largely in the study and planning stage for the time being.

Coordination and Reporting

As indicated by the present early planning, research and applications of weather modification are broad and varied in scope, and have the interest of many agencies. Even at this stage coordination is imperative, and with the passage of time coordination will become ever more important to sound planning and effective execution of the program. It is clear that research and applications of weather modification are closely related to meteorological services and supporting research; indeed, it would be an artificiality to attempt to separate them. Hence, I recommend that the Federal Coordinator, who already has responsibility for coordination and reporting in this area of meteorology, undertake coordination of the National Weather Modification Program in addition to the coordination of national activities in meteorology.

By "coordination" I mean largely "correlation," including documenting and tabulating in one place, and analyzing existing government program activity, providing for all concerned a continuing visibility of the whole national weather modification effort. It is intended to assign the same kind of responsibility in weather modification that the Federal Coordinator now has for meteorology. Such a well organized program of central correlation of program activities may be expected to lead to agreements and arrangements among the agencies on such things as joint purchase of materials and equipments, common support and use of facilities, joint field operations, elimination of undesirable duplications in the establishment of observing nets, etc. It is not intended to give the Federal Coordinator responsibility for program planning or control. These would continue to be the responsibilities of the operating agencies and under the review of ICAS. The overall result would be an effectively coordinated program.

I also feel that the Federal Coordinator for Meteorology should be assigned the task of preparing and submitting an annual report on national weather modification activities. This reporting assignment is at present by law given to the National Science Foundation. I believe that it is desirable to relieve NSF of this burden. For one thing, the principal future of weather modification activities is directed toward applied research and operations, which are not and should not be in the mainstream of NSF's responsibilities for basic research. Secondly, as has already been pointed out, weather modification research and operations are inextricably interwoven with meteorological service and supporting research. Requiring the Federal Coordinator for Meteorology to report on the national weather modification effort, therefore, appears to be a natural step.

Regulation and Control

As brought out clearly by the NSF Special Commission Reports (Refs. 2 and 3), the subject of regulation and control in weather modification is a complex and urgent one. I do not feel that I can recommend a specific organization to be assigned the responsibility for regulation and control of weather modification activities. I do, however, have a few related recommendations.

I feel very strongly that the regulating body must not be one of the operating agencies participating in the National Weather Modification Program. To assign this responsibility to one of these agencies would immediately generate conflicts of interest, sow the seeds of dissension, and doom the efforts at regulation and control to endless frustration.

I feel that the regulating body should not be the Interdepartmental Committee for Atmospheric Sciences (ICAS). In my view, the regulation and control function will be a full-time task for a modest staff of people, particularly, as the national weather modification effort increases and as activities become international in scope. ICAS is in no position to undertake such a full-time assignment. Moreover, many of the conflict-of-interest problems that arise in the case of assigning the function to one of the operating agencies would also exist in such an assignment to ICAS.

Were the Office of the Federal Coordinator for Meteorology more clearly separate from ESSA, and perhaps even from the Department of Commerce, one might assign this task to the Federal Coordinator. I feel very strongly, however, that the present relations between the Federal Coordinator's office and ESSA are sufficiently ambivalent to make the assignment of the regulation and control function to the Federal Coordinator an unwise step.

International Implications

By approximately 1972, when large-scale weather modification experiments may well be operational, they may be expected to have considerable international impact. This impact will be twofold:

(1) As experiments and operations become geographically more extensive, there will be a need for coordinating such operations with nations whose territories are affected by those operations. If experiments take place over oceans there may be a conflict with weather modification experiments by other nations. This is essentially a question of regulation and coordination. It is not expected that an international regulatory body will exist by that time. Indeed, efforts

to establish an international agency to deal with weather modification, while well intended, are likely to be of dubious value and to create rather than resolve political problems--if the experience in nuclear energy and space is any guide.

A more practical and constructive approach to the international problem--and one which should pave rather than block the way for the necessary experimentation--would be through bilateral or multilateral arrangements. In these, the U.S. would seek to establish the mutual interest of neighboring countries in large-scale experiments and to engage them with us in such experiments. In this way, we could educate a growing number of countries, establish our good faith, increase the acceptability of the program in the eyes of third countries, demonstrate values transcending national interests, and win support where required in international forums which may address themselves on a political basis to the problems of weather modification.

The office for regulation and control, discussed in the preceding section, will certainly have to be involved. National responsibilities will have to be clarified and defined. This, however, is a subject outside the scope of my assignment.

(2) Benefits and potential payoffs of weather modification experiments on a national scale have already been discussed in the introduction to this report. When applied on a global scale these benefits could increase greatly. For example, modification and diversion of tropical storms or typhoons in the Western Pacific or

Indian Ocean would result not only in the prevention of property damage several orders of magnitude greater than in North America, but also, and more importantly, in the saving of countless numbers of human lives. Similar benefits would occur from precipitation augmentation by relieving large areas from the effects of extensive droughts. Thus, valuable experience gained initially on a smaller, national scale, may eventually be important internationally, permitting us to cooperate with and assist other countries in the saving of human lives and property, and in the enhancement of human welfare. This is another of the benefits that may result from a vigorous national program such as that discussed in the preceding sections.

Concluding Statement

It is believed that the plan I recommend herein would permit the development of a National Weather Modification Program with a satisfactory forward thrust at a realistic pace, would provide interested agencies with a substantial and satisfying involvement, would make good use of the experience and interest of the various agencies, is consistent with assigned agency responsibilities, can develop into a well-coordinated and integrated national program, and should avoid potential conflicts.

REFERENCES

1. Final Report of the Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences, National Academy of Sciences-National Research Council; "Weather and Climate Modification, Problems and Prospects," Volume I- Summary and Recommendations, Volume II- Research and Development, Publication No. 1350, 1966

2. Report of the Special Commission on Weather Modification, National Science Foundation; "Weather and Climate Modification," Publication No. NSF 66-3, transmitted to NSF December 20, 1965

3. Report to the Special Commission on Weather Modification, National Science Foundation; "Weather Modification Law, Controls, Operations," Publication No. NSF 66-7 (no date)

APPENDICES

I Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences, National Academy of Sciences-National Research Council; Membership and Recommendations

II Special Commission on Weather Modification, National Science Foundation; Membership and Recommendations

III Report prepared by the ICAS Select Panel on Weather Modification; "Present and Future Plans of Federal Agencies in Weather-Climate Modification," dated June 20, 1966

IV Memorandum for Dr. Homer E. Newell from J. Herbert Hollomon, Chairman, ICAS, Subject: National Weather Modification Program, dated June 21, 1966

V NASA Panel to Study Weather Modification Activities; Membership, Chronology of Meetings, and a Compilation of Supporting Material used by the Panel

VI Budget Recommendations and Trends for a National Weather Modification Program

PANEL ON WEATHER AND CLIMATE MODIFICATION

to the

Committee on Atmospheric Sciences

NAS-NRC

MEMBERSHIP

RECOMMENDATIONS

APPENDIX I

PANEL ON WEATHER AND CLIMATE MODIFICATION
to the
Committee on Atmospheric Sciences, NAS-NRC

Gordon J. F. MacDonald, University of California at Los Angeles, Chairman

Julian H. Bigelow, Institute for Advanced Study

Jule G. Charney, Massachusetts Institute of Technology

Ralph E. Huschke, The RAND Corporation

Francis S. Johnson, Southwest Center for Advanced Studies

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Edward N. Lorenz, Massachusetts Institute of Technology

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*Joanne Simpson, Environmental Science Services Administration

Joseph Smagorinsky, Environmental Science Services Administration

Verner E. Suomi, University of Wisconsin

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LIAISON MEMBERS

Donald L. Gilman, Environmental Science Services Administration

Edward P. Todd, National Science Foundation

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PANEL ON WEATHER AND CLIMATE MODIFICATION
to the
Committee on Atmospheric Sciences
National Academy of Sciences - National Research Council

AREAS AND RECOMMENDATIONS

Administration and Funding of Research and Development in Weather Modification

We recommend an immediate and thorough study of the administration and support of research and development in weather modification.

We recommend that immediate steps be taken by the agencies to raise the support from the 1965 level of $5 million to at least $30 million by 1970.

Projects in Stimulation of Precipitation

We recommend the early establishment of several carefully designed, randomized, seeding experiments, planned in such a way as to permit assessment of the seedability of a variety of storm types.

We recommend, therefore, that means be found, at federal expense if necessary, to secure much better evaluative reports on operational programs than are currently available.

We recommend that attention be given immediately to careful monitoring and regulation of operational programs for weather modification.

Research Properties

We recommend that planning be started immediately on all the following major field investigations:

a. A comprehensive exploration of hurricane energetics, leading to the development of a theoretical hurricane model and, subsequently, to hypotheses for hurricane modification.

b. Measurement of tropical convection and other aspects of energy-exchange processes in the tropics.

c. A comprehensive investigation of hailstorms.

d. A coordinated set of projects to measure the dynamics and water budgets of a variety of precipitating storm types.

e. It is clear that research throughout the atmospheric sciences will contribute to the goals of weather and climate modification. Of the research promising the most direct contributions, we recommend that highest priority be assigned to the following studies:

1. Studies of atmospheric water budgets, initially on vapor transport over those portions of the United States where the potential of cloud seeding is important.

2. Studies of boundary-layer energy-exchange processes.

3. Continued development of theoretical models of condensation and precipitation mechanisms, including the early incorporation of dynamical and electrical influences and the effects of changes in concentrations of condensation and freezing nuclei.

4. New and comprehensive studies of the meteorological effects of atmospheric pollution (including carbon dioxide) and urbanization.

Major Research Facilities and Support Systems

We recommend that all necessary steps be taken to encourage the computer industry to respond to these prospective requirements.

We recommend full U.S. support and leadership in promptly establishing an advanced global-observational system.

We recommend that the civil research aircraft facilities be enlarged to include diversified types of aircraft and supporting data-gathering systems to meet the requirements placed upon them.

Internal Aspects

We recommend that the federal agency assigned major administrative responsibilities in this field also be empowered to deal with the complex international issues arising from weather-modification projects.

SPECIAL COMMISSION ON WEATHER MODIFICATION

National Science Foundation

MEMBERSHIP

RECOMMENDATIONS

APPENDIX II

SPECIAL COMMISSION ON WEATHER MODIFICATION
National Science Foundation

A. R. Chamberlain, Chairman, Vice President, Colorado State University

John Bardeen, Vice Chairman, Departments of Physics and Electrical Engineering, University of Illinois

William G. Colman, Executive Director, Advisory Commission on Intergovernmental Relations

John C. Dreier, School of Advanced International Studies, The Johns Hopkins University

Leonid Hurwicz, Department of Economics, University of Minnesota

Thomas F. Malone, Second Vice President, Research Department, Travelers Insurance Company

Arthur W. Murphy, Columbia University School of Law

Sumner T. Pike, Lubec, Maine

William S. von Arx, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution

Gilbert F. White, Department of Geograpny, University of Chicago

Karl M. Wilbur, Department of Zoology, Duke University

SPECIAL COMMISSION ON WEATHER MODIFICATION
National Science Foundation
CONCLUSIONS AND RECOMMENDATIONS

Progress and Prospects in Weather and Climate Modification

The Commission concludes that sound progress toward the technology of weather and climate modification must be based on four fundamental pursuits:

a. Assessment and development of an understanding of natural climatic change.

b. Assessment of the extent and development of the understanding of inadvertent modifications of weather and climate.

c. Improvement of the process of weather prediction as a social benefit and as proof of scientific understanding of atmospheric behavior, and

d. Development of means for deliberate intervention in atmospheric processes for weather and climate control and evaluation of their consequences.

As steps toward these attainments the Commission recommends that the following enterprises be fostered:

1. Examination of the routes, rates, and reservoirs of water substance and energy exchanges in all aspects of the hydrologic cycle.

2. Investigation by numerical laboratory and field experiments of the dynamics of climate as a basic study for weather modification technology.

3. Advancement of weather prediction as a proof of understanding, including support of this effort by the establishment of a global weather observation network.

4. Broadening of the knowledge of cloud physics and dynamics in the laboratory and field, with attention to wave phenomena and an evaluation of electrical influences.

5. Study of the effects of large scale surface modification by numerical and laboratory models of the oceanic and atmospheric general circulation, and of practical means for surface modification of the land and sea.

6. Study of the radiative effects of changes in the atmospheric composition and alteration of its transparency that urban growth and new forms of industry, transportation or land use may evoke.

Biological Aspects of Weather Modification

Living things are adapted to the weather that actually prevails, and any change in that weather will be generally deleterious to them.

The largest credit item for weather modification is likely to be an increase in primary production of the drier parts of the land surface through improvements in rainfall. Even the ability to control seasonal distribution of rainfall would lead to more efficient farming operations. Realization of the potential increase in production would depend upon being able to modify the rainfall without major pest outbreaks and extinction and disruption of natural communities. It is not certain that this would be possible.

The largest weather modification debit item is likely to spring from the decreased stability of communities, which would manifest itself in an increase in pests, weeds, and pathogens. The identity of the species involved in these disruptions cannot be predicted, nor can their cost.

For the present, weather and climate modification should be restricted to local small-scale operations.

Larger scale operations, such as an attempt to increase the rainfall of any substantial part of this country, should not be undertaken, from a biological point of view, in the present state of knowledge.

All weather modification experiments of a scale large enough to have important biological consequences, such as those currently envisioned for the Upper Colorado Basin, should be preceded and accompanied by careful ecological monitoring and computer simulation studies. Manipulating the weather to obtain a net benefit will demand much better understanding of the interactions of weather, climate and organisms than now available.

Adequate understanding of the interrelationship of weather, climate and ecology will demand a very expensive long-term research program. Present resources of ecologically trained investigators are inadequate to cope with these problems.

The Working Group of the Ecological Society of America, which provided background material for the Commission, was concerned primarily with modifications of weather systems ranging from a single cloud to an extratropical cyclonic storm. The Working Group stated that short-term modifications of weather of a magnitude similar to the fluctuations in nature are least likely to have dangerous unforeseen consequences. If undesirable results appear, the modifications can be discontinued.

Repeated operations on the scale mentioned are likely, however, to have far reaching biological consequences as pointed out in the previous sections, and some of the biological changes would not be reversible. This advisory group recommended that repeated and long term modifications of weather not be attempted without prior careful and well planned monitoring or computer simulation studies of the biological consequences of particular kinds of weather modification.

Statistical Aspects of Weather Modification

Statistical training for meteorologists should be promoted in academic programs. Intellectual interchange between scientists and statisticians should be continued through periodic seminars.

Statistical consultants should be made available to scientists in this field through the support of conferences where new projects can be presented, through use of statisticians as evaluators of proposed work, and through the support of task forces and advisory panels, with statistician members, for large projects. Statisticians should aid in the evaluation of proposals for government-supported research.

Steps should be taken to assure that plans for government-supported research utilize statistical principles in determination of design and size.

Research in methodology should be promoted. This includes the development and validation of statistical models, uniformity trials and other investigations of the statistical characteristics of the instrumentation in this work.

It is urged that any regulatory agency that might come into being should have a staff statistician to guide efforts to gather valid evidence on the magnitude and effects of cloud seeding.

A program of carefully planned precipitation-oriented field experiments should be carried out under complete control of the scientists, embodying the required technical knowledge, possessing continuity over a period needed for conclusiveness, and on sufficient scale to permit geographic conclusions, as well as statistical stratification according to the type of seeding agent, mode of injection, cloud type, etc.

The Human Effects of Weather and Climate Modification

Steps should be taken to assure that wherever field experimentation or commercial operations are undertaken in weather and climate modification arrangements be made to study the social consequences.

A special panel should be established to exchange and give critical review to the results of such studies.

The method of assessing impacts of weather modification should be the subject of research looking to its refinement and extension.

Freedom of field experimentation should be supported by providing indemnification of Federally financed experimenters against damage claims.

Research should be encouraged on the basic relationships between weather characteristics and human activity.

Decision making processes in the face of uncertainty as to weather modification and its effects should be subjected to careful investigation as a means of increasing the government's ability to predict the results of alternative policies and methods for weather modification.

Interdisciplinary study of modifications which man makes inadvertently should be encouraged.

Legal and Legislative Aspects

The Commission recommends that the Federal Government by appropriate legislation be empowered to:

1. Delay or halt all activities -- public or private -- in actual or potential conflict with weather and climate modification programs of the Federal government, whether carried on by the government itself or by its grantees or contractors;

2. Immunize Federal agents, grantees, and contractors engaged in weather and climate modification activities from State and local government interference; and

3. Provide to Federal grantees and contractors indemnification or other protection against liability to the public for damages caused by Federal programs of weather and climate modification.

Weather Modification and International Relations

The Commission believes that it would be highly desirable for the Government of the United States, in connection with the expansion of its program of weather and climate modification, to issue a basic statement as to how it views the relationship of this new national effort to the interests, hopes, and possible apprehensions of the rest of the world. The Commission further believes that emphasis upon international cooperation in the development of weather and climate modification programs will contribute substantially to scientific and technical progress and will also serve the national purpose of seeking to build a peaceful world order.

The Commission recommends the early enunciation of a national policy embodying two main points: (1) that it is the purpose of the United States, with normal and due regard to its own basic interests, to pursue its efforts in weather and climate modification for peaceful ends and for the constructive improvement of conditions of human life throughout the world; and (2) that the United States, recognizing the interests and concerns of other countries, welcomes and solicits their cooperation, directly and through international arrangements, for the achievement of that objective. This cooperation should cover both research and operational programs of interest to other countries. It should be concerned not only with deliberate but also inadvertent human interventions in the atmosphere that affect weather and climate. Such a policy declaration could be issued by the President or incorporated in any basic legislation on the subject of weather and climate modification which the Congress may enact.

Funding and Administration Requirements

The Commission has considered carefully the problems attendant upon the assignment of responsibility for weather and climate modification activities within the Executive Branch of the Federal Government.

There are no easy solutions to these questions. The Commission believes the adoption of the following recommendations would significantly improve the effectiveness of the Nation's efforts in this field, and would facilitate the achievement of the scientific and other objectives specified elsewhere in this report.

a. Responsibility for Research, Development, and Operations

The Commission recommends: (1) the assignment of the mission of developing and testing techniques for modifying weather and climate to a single agency in the Executive Branch of the Government - for example to the Environmental Science Services Administration of the Department of Commerce or to a completely new agency organized for the purpose; (2) the continuance and expansion of research in the atmospheric sciences by the National Science Foundation, including its program directed at providing a satisfactory scientific basis for weather and climate modification and the maintenance of the National Center for Atmospheric Research as a basic research facility for this purpose; and (3) the conduct or support, pursuant to Executive Order 10521, of such basic and applied research by other Federal agencies as is required for their varied missions as well as the conduct of operational activities necessary for the accomplishment of such missions (e.g., precipitation augmentation for the reservoir system of the Bureau of Reclamation; lightning suppression by the U.S. Forest Service; military applications by the Department of Defense; etc.).

The degree of the Foundation's special attention to this field, including the support of related research in other affected disciplines, should be reviewed from time to time in the light of the progress of the overall national program. The Foundation needs to continue the vigorous support of basic research in the atmospheric sciences because fundamental knowledge so derived is a necessary underpinning to technological progress in weather and climate modification.

The agency assigned the mission of developing and testing techniques for modifying weather and climate, as a part of its overall mission, should have major but not exclusive responsibility in collaboration with the State Department for formulating and implementing weather and climate modification programs involving international collaboration with the governments of other nations. The government's activities in international cooperation can be substantially assisted by the participation of the National Academy of Sciences.

. Regulation

The Commission recommends that responsibility for appropriate Federal regulation of weather and climate modification activities to aid the Federal Government's program of research and development and to protect the general public be kept separated from research and development activities while assuring prompt and full availability to such activities of data derived from the regulation of commercial and other operational activities. Such a combination might be achieved, for example, by assigning the regulatory function to some part of the Department of Commerce not concerned with weather and climate research and development.

Earlier in this report there has been discussed the nature of minimum regulatory action which may be required on the part of the national Government to assure the integrity of experiments conducted by Federal agencies or their grantees and contractors. It should be pointed out in this connection that Federal agencies and their contractors and grantees themselves will necessarily be subject to some of the same types of regulation that apply to commercial operations. A Federal agency field experiment involving large-scale cloud seeding for example, can cause the same interference with other scheduled experiments as can cloud seeding conducted by a commercial operator.

Consequently, Federal agencies will need to be subject to many of the rules and regulations issued by the type of regulatory unit recommended above. Insofar as the regulation involves requirements of notice of experiments, licensing of activities and the like, there would seem to be reason why all Federal agencies should be subject thereto. The regulating agency should also have the power to resolve minor conflicts between agencies, such as the precise timing of particular experiments. Any major disagreements would involve policy and administrative coordination as discussed below.

c. Inter-Agency Coordination of Policies and Program Activities

The Commission recommends that there be established within the Office of Science and Technology (OST) a special mechanism for the coordination of weather and climate modification programs and for recommending such steps as may be appropriate for effecting a unity of governmental policy in this field.

If the general mission of developing the technology for climate modification is assigned to a single agency, present overlap and lack of concerted effort among the various agencies will be remedied to a considerable extent. Due to the great importance of the field, however, and because of the necessity of maintaining an interdisciplinary and international approach to weather activities, it is believed that continuing attention must be forthcoming from the Executive Office of the President. Consequently, some mechanism concerned solely with weather and climate modification, with emphasis on the development and operational side, needs to be established within the OST. The OST's concern should embrace funding, basic research, applied research, development, testing and evaluation. Such a mechanism could take over from ICAS the weather and climate modification components. ICAS could continue to be concerned with atmospheric research.

d. An Advisory Committee

The Commission also recommends the utilization of the National Academy of Sciences and the National Academy of Engineering for continuing review and advice regarding the national program of weather and climate modification.

Both the President's Science Advisory Committee and the Congress need to be able to obtain scientific and public policy advice from a group of knowledgeable people from outside the Government. This need could perhaps be met by the appointment of a standing committee in the National Academy of Sciences in cooperation with the National Academy of Engineering. Such a committee includes persons with experience in the physical sciences, engineering, the biological sciences and the social sciences.

Report to the
Interdepartmental Committee on Atmospheric Sciences

PRESENT AND FUTURE PLANS OF FEDERAL AGENCIES IN WEATHER-CLIMATE MODIFICATION

June 20, 1966

Prepared by the ICAS Select Panel on Weather Modification

FOREWORD

This report was prepared by the ICAS Select Panel on Weather Modification for consideration by the Interdepartmental Committee on Atmospheric Sciences as requested by the Chairman at the May 13, 1966, meeting. It presents a budget summary of the goals, program approach and facilities of the Federal Departments and Agencies engaged in weather and climate modification activities for FY 1967 and FY 1970. A brief summary statement by each Department or Agency is also included to supplement the budgetary material.

Attention is invited to the following points of interest illustrated by the matrix presentation.

1. The primary emphasis of the Federal goals in weather modification appears to be in the category of precipitation modification.

   FY 1967 $4.70 million out of $9.33 million total
   FY 1970 $99.60 million out of $146.83 million total

2. The largest percentage and over-all increases from FY 1967 to FY 1970 in weather modification are planned by ESSA and the Bureau of Reclamation.

   ESSA - $1.55 million in 1967 to $59.70 million in 1970
   Bureau of Reclamation - $3.00 million in 1967 to $70.00 million in 1970

3. The Department of Agriculture is planning to support a reasonably broad-based weather modification program by FY 1970 (from $0.5 million to $9.35 million) expanding into hail suppression, biological aspects, and boundary layer exchange.

4. The Department of Defense is holding level and will not expand significantly unless a mission breakthrough is imminent.

5. Field experiments show as one would expect--very expensive.

Earl G. Droessler
Chairman, ICAS Select Panel
on Weather Modification

June 20, 1966

WEATHER MODIFICATION GOALS $\frac{1967}{1970}$ (millions)

Agency	Fog and Cloud Dissipation	Precipitation Modification	Hail Suppression	Lightning Modification	Severe Storm Modification	Other (climate, boundary layer, etc.)	Socio-Economic Biological Legal	TOTAL	Inadvertent Modification
AGRIC.	-	-	0.015	0.140	-	0.225	0.115	0.495	-
	-	-	1.700	1.000	-	*3.400	3.250	9.350	-
ESSA	0.100	0.300	0.140	0.180	0.660	-	-	1.380	0.170
	0.400	27.100	5.200	4.900	12.200	#7.100	0.700	57.600	2.100
DOD	0.930	-	-	0.090	0.210	-	-	1.230	0.050
	1.030	-	-	0.110	0.240	-	-	1.380	0.060
BUR.	-	3.000	-	-	-	-	-	3.000	-
REC.	-	70.000	-	-	-	-	-	70.000	-
NSF	0.200	1.400	0.700	0.200	0.200	0.200	0.100	3.000	0.214
	0.500	2.500	1.650	0.500	0.750	0.500	1.000	7.400	0.500
NASA	0.070	-	-	-	-	-	-	0.070	-
	0.150	-	-	-	-	-	-	0.150	0.020
FAA	0.130	-	-	-	-	-	0.020	0.150	-
	0.950	-	-	-	-	-	-	0.950	-
TOTAL	1.430	4.700	0.855	0.610	1.070	0.425	0.235	9.325	0.434
	3.030	99.600	8.550	6.510	13.190	11.000	4.950	146.830	2.680

* includes boundary layer studies and remote sensing.
\# includes climate modification studies and cumulus modification.

WEATHER MODIFICATION PROGRAM APPROACH $\frac{1967}{1970}$ (millions)

Agency	Field Experiments	Laboratory Studies	Statistical Studies	Theoretical Research	Development of Technology	Systems Development	Other (legal, social, biological, etc.)	TOTAL
AGRIC.	0.275	0.020	0.020	0.020	0.045	-	0.115	0.495
	3.910	0.450	0.185	0.500	0.695	0.360	3.250	9.350
ESSA	0.830	0.150	0.035	0.100	0.180	0.155	0.100	1.550
	39.350	11.450	1.050	4.950	1.050	1.150	0.700	59.700
DOD	0.730	0.180	0.030	0.170	0.120	-	-	1.230
	0.810	0.200	0.040	0.190	0.140	-	-	1.380
BUR.	2.009	0.102	0.186	0.090	0.365	0.213	0.035	3.000
REC.	45.000	4.500	7.000	1.500	9.000	2.000	1.000	70.000
NSF	1.500	0.700	0.050	0.575	0.075	-	0.100	3.000
	4.000	1.000	0.200	0.800	0.400	-	1.000	7.400
NASA	0.005	0.030	-	0.030	0.005	-	-	0.070
	0.070	0.030	-	0.010	0.040	-	-	0.150
FAA	-	-	-	-	0.130	-	0.020	0.150
	-	-	-	-	-	0.950	-	0.950
TOTAL	5.349	1.182	0.321	0.935	0.920	0.368	0.370	9.495
	93.140	17.630	8.475	7.950	11.325	4.460	5.950	148.930

FACILITIES FOR WEATHER MODIFICATION $\frac{1967}{1970}$ (millions)

Agency	Cloud Chambers	Aircraft (purchase, rental, instrumentation)	Aircraft (operating costs)	Observational Networks (instruments)	Radar for Weather Mod.	Laboratory Equipment	Cloud-Seeding Equipment	Computers for Weather Mod. (purchase - rental)	Other	TOTAL
AGRIC.	-	0.060	0.070	0.040	0.030	0.035	0.005	0.010	-	0.250
	-	0.220	0.350	0.950	0.300	1.880	0.100	0.200	-	4.000
ESSA	0.050	0.020	0.200	0.050	-	0.075	0.050	-	0.010	0.455
	8.000	13.100	11.300	4.400	2.600	2.000	0.800	-	-	42.200
DOD	0.040	0.060	*0.300	0.020	0.010	0.110	0.050	-	-	0.590
	0.050	0.070	*0.330	0.020	0.010	0.130	0.060	-	-	0.670
BUR.	-	0.250	0.015	0.500	0.015	0.020	0.060	-	-	0.860
REC.	1.250	6.000	0.500	2.000	3.000	0.750	1.000	1.500	-	16.000
NSF	0.200	0.080	0.045	0.165	0.070	0.080	0.012	0.085	-	0.737
	0.500	0.250	0.100	0.300	0.100	0.100	0.050	0.200	-	1.600
NASA	-	-	-	-	-	0.010	-	-	-	0.010
	-	-	-	-	-	0.015	-	-	-	0.015
FAA	-	-	0.010	0.005	-	-	-	-	-	0.015
	-	-	0.040	0.050	-	-	-	-	-	0.090
TOTAL	0.290	0.470	0.640	0.780	0.125	0.330	0.177	0.095	0.010	2.917
	9.800	19.640	12.620	7.720	6.010	4.875	2.010	1.900	-	64.575

* includes research aircraft only.

DEPARTMENT OF AGRICULTURE
WEATHER MODIFICATION PROGRAM FOR FY 1967

The Department of Agriculture is performing or planning weather modification research in five major fields:

(1) Lightning suppression
(2) Hail suppression
(3) Biological responses to weather modification
(4) Boundary layer energy exchange
(5) Remote sensing in support of weather modification

Present Program.

(1) Lightning Suppression. Project Skyfire of the U. S. Forest Service is performing an active research program aimed at suppression of lightning. Field experiments are testing the effects of very heavy seeding with silver iodide on lightning storms. The results to date show that seeded clouds produced 1/3 fewer cloud-ground strokes than non-seeded clouds. The type of lightning discharge most likely to ignite forest fires has also been identified. Physical and mathematical models of mountain thunderstorms are being developed.

(2) Hail Suppression. The main activity is preliminary planning of a long range research program. Statistical studies are being made of hail damage to agricultural crops and related resources.

(3) Biological Responses to Weather Modification. The Forest Service and Agricultural Research Service are engaged in ecological studies giving consideration to individual species under a limited range of climatic parameters. These studies are developing information on both forest and farm biological communities in relation to specific features of weather and climate.

(4) Boundary-Layer Energy Exchange. The Department of Agriculture has had long and productive research related to boundary-layer energy exchange. These studies concern the energy response of evapotranspiration. Limited studies are underway of energy exchange relationships under specific atmospheric situations.

(5) Remote Sensing in Support of Weather Modification. The Forest Service and Agricultural Research Service are performing research for development of knowledge and technology in remote sensing as applied to agricultural and forestry programs. Part of the activities support development of the weather modification research program. Airborne infrared scanners are being used to provide information on fires, vegetation, topographic features and background thermal radiation. Advanced photographic techniques are being developed. Planning is underway for an expanded research program for remote sensing of biomass changes on agricultural and forest lands and detection of critical changes in boundary-layer energy exchange relations.

(1) Lightning Suppression. On the foundation of the results stemming from Project Skyfire, the Forest Service is planning a strengthened research program including:

(a) Expanded field experiments will permit instrumentation of a larger area, intensification of measurement of lightning discharges, and delivery of larger quantities of silver-iodide to storms selected for treatment. Research will be stepped up on the development of higher output silver iodide generators for use on aircraft and at ground stations. Experimental capabilities will be increased to permit simultaneous seeding of two or more cloud systems in instrumented test areas.

(b) More intensive investigation of the already identified lightning stroke most likely to ignite fires and of the physical processes for its modification is planned. Strengthened laboratory experiments will accelerate investigations of the modification of the electrical structure of simulated clouds with freezing nuclei.

(2) Hail Suppression. A research program consisting of four major activities is proposed: (1) The Forest Service, utilizing technology already developed by Project Skyfire, would initiate basic studies of hailstorm phenomena and field experiments in the seeding of hailstorms; (2) Agricultural Research Service would undertake studies of the relationships between hailstorms and the production and quality of agricultural crops; (3) Economic Research Service would examine the socio-economic aspects of hailstorms; and (4) Cooperative State Research Service would establish a grant program for hail research with universities.

(3) Biological Responses. The research program proposed would provide a centrally coordinated effort directed at meeting the glaring deficiencies in ecological knowledge. In an area in which weather is to be modified, natural communities would be selected for study and permanent plots established in them. Communities would be chosen to represent the full range of environments and major community types in the area and especially in extreme environments. Detailed observations would be made before, during, and after a period of weather modification to determine species changes. Similar plots in similar situations would be established and observed in natural areas unaffected by weather modification or by other of man's activities. Particular attention would be given to certain insect pests, weed species, species near the limits of their range, and to soil fauna and flora. Indicator species would be sought.

The proposed program would include computer simulation studies.

The research plan would include a continuing comprehensive analysis of precipitation data to determine if a measurable beneficial or detrimental effect occurred anywhere within the system. Concurrently, there would be comprehensive controlled ecological studies on the effect on vegetation of different amounts and patterns of precipitation.

(4) Boundary-Layer Energy Exchange. The effect of changing the amount of advected energy through weather modification upon the processes at the leaf-air interface will be evaluated and procedures developed to minimize the effect of spreading droughts, or to take advantage of benefits from weather modification.

Microclimate control measures will be developed to reduce evapotranspiration, to conserve soil moisture reserves, and to assure adequate photosynthetic activity of cropped and forested areas.

The effects of weather modification on diffusion and eddy transfer processes that are responsible for the exchange of carbon dioxide, water vapor, and heat between leaf surfaces and the atmosphere will be clarified.

(5) Remote Sensing. Research will be conducted to:

(a) Develop technology to determine ecologic changes of past 20 years related to inadvertent weather modification. Modern sequential aerial photography compared with early photography can provide some pre-weather modification bases for measuring current and future trends.

(b) Develop scaling laws and change detecting systems by multiscale remote sensing which starts at the milacre plot and scales upwards to satellite-scale high resolution remote sensing.

(c) Develop technology of detecting and measuring trends in biomass and its characteristics and trends in characteristics significant to energy-balance.

ESSA'S PLANNED WEATHER MODIFICATION RESEARCH PROGRAM FOR FY 1967

Research planned by the Department of Commerce Environmental Science Services Administration during fiscal year 1967 will be directed to an expanded "in house" and contractual program of instrument and equipment development, field measurements and experiments, laboratory investigations, theoretical modeling of cloud physics processes, and establishment of a bench mark program of data collection related to inadvertent weather modification. An expanded exploration of the structure and dynamics of hurricanes through experiments designed to inquire into the feasibility of storm modification by sustained and massive seeding techniques is programmed in collaboration with the U. S. Navy (Project STORMFURY).

The conceptual foundations for hail suppression or modification will be examined through use of a newly constructed mobile hail laboratory operated by the ESSA Atmospheric Physics and Chemistry Laboratory recently established at Boulder, Colorado. A series of surface and airborne measurements and experiments will be carried out near Flagstaff, Arizona, during July and August 1966 in cooperation with the U. S. Army lightning suppression research project. The experiments incorporate chaff seeding techniques and the effects of this on cumulus cloud electrification will be assessed on the basis of ground level and aircraft surveillance of atmospheric electrical parameters. Instrument and equipment development will include a raindrop spectrometer, airborne humidity and temperature sensing devices, and the construction of an aircraft mounted system for releasing large quantities of hydrophilic substances for altering the natural population of condensation nuclei.

A series of field experiments intended to critically study the precipitation augmentation and redistribution problem is being planned with particular reference to the Northeastern U. S. and Great Lakes region as a follow-on research program recommended by the National Academy of Sciences Panel on Weather and Climate Modification. The program will include field experiments designed to clarify the vertical and horizontal diffusion of silver iodide released from ground generators. Theoretical modeling experiments and laboratory research will heavily emphasize cloud nucleation problems and the role of precipitation formation and growth mechanisms in altering cloud dynamics or processes initially under tropical convective regimes. Problems of inadvertent weather modification will be approached by establishing a sustained standardized carbon dioxide monitoring program initially at the remote high altitude Mauna Loa Observatory in Hawaii to provide a bench mark series of data.

ESSA'S PLANNED WEATHER MODIFICATION RESEARCH PROGRAM FOR FY 70

Fiscal year 1970 is the middle year of the proposed ESSA five-year weather modification program. The major field projects will be reaching full operating strength, and the expenditures for heavy capital equipment will reach a peak during this year. The exploratory phase of the effort will have been under way for the previous two years, and it is to be hoped that experimental application of modification techniques could begin in most areas.

Documentation of the cloud and precipitation structure during both winter and summer months will have been achieved over most of the experimental sites, and experimental seeding operations will be under way primarily by aircraft, for establishing optimum techniques for precipitation control. Ground-based randomized seeding at several sites will be continued. Exploration of severe storms--hurricanes, tornadoes, hailstorms--will continue, directed at the establishment of modification hypotheses. Experimental treatments will be employed as appropriate. The background research effort will continue, with emphasis on laboratory studies, computer simulation, and field observations and experiments. Large-scale dynamic modeling will represent an expanding effort, with the creation of more sophisticated models as computer capabilities increase. Instrument development will continue at an accelerating pace, with emphasis on radar, aircraft equipment, and the concept and development of entirely new approaches to cloud and atmospheric measurements. Studies of future operational system concepts will be initiated.

The major outlay in new facilities would continue to be in the purchase of aircraft. According to the proposed ESSA five-year program two additional P-3 (Electra), two additional executive type, and one heavily stressed military attack aircraft, are scheduled for 1970. With completion of design studies, it is planned that construction of at least two large-scale cloud chambers would begin during this year. Also, if the desirability of a new national laboratory were established, construction of this facility would also be undertaken. Field site instrumentation would be continued, primarily to fill out planned complements, and to install new types of equipment which had been developed during the first two years of the program.

DEPARTMENT OF DEFENSE WEATHER MODIFICATION PROGRAM FOR FY 1967

DOD's interest in weather modification is not a general across the board interest in weather modification as a science or even in the broad improvement in technology. It is rather an interest in those particular scientific and technological areas that have direct application to the improvement of DOD's capability for carrying out its mission.

The main thrust of the DOD effort in weather modification can be divided into four major problem areas. These are:

WARM FOG

The problem of warm fog and stratus receives the major emphasis in the DOD weather modification program due to its widespread occurrence and its adverse effect on so many military operations.

Although a number of approachs have been made in attempting to dissipate warm fogs and one technique involving the application of vast quantities of heat has demonstrated a measure of success there is at present no economically and operationally feasible method available for general use. The major portion of the DOD efforts in this area are therefore directed toward gaining a better understanding of the life cycle of warm fogs in terms of physical parameters the knowledge of which will be necessary to develop feasible dissipation techniques.

SEVERE STORM MODIFICATION

The need for finding a way to moderate the intensity of the most violent forms of nature is obvious. The most ambitious attack on this problem in which DOD is involved is the joint DOD-DOC program for experiments on hurricane modification known as Project STORMFURY.

CONVECTIVE CLOUDS

The two areas of interest just discussed account for 80% of the funds devoted by DOD to weather modification. Another area of interest is the broad topic of convective clouds. This is of major interest not only because of its association with severe storms but also because it is the dominant type of activity in tropical regions where much of DOD's area of operations is centered.

COLD FOG

This activity accounts for only 5% of the research effort mainly because it has moved into operational use in DOD. Research is continuing, however, on more efficient modification techniques such as the use of propane gas or the transportation of dry ice by small balloons.

Associated with these problem areas and necessary to their eventual solution is the work being carried out in cloud physics and instrumentation development in report of more general problems in the atmospheric sciences.

DEPARTMENT OF DEFENSE WEATHER MODIFICATION PROGRAM FOR FY 1970

The DOD weather modification program is funded under a level effort concept and unless a major technological breakthrough is achieved or a critical unforeseen need arises the program should remain at its present level. Dollar amounts may increase over the next several years due to the general increase in cost of living which at this time amounts to between 3-4% per year but no major expansion of the program is planned at present.

BUREAU OF RECLAMATION WEATHER MODIFICATION PROGRAM FOR FY 1967

Field experiments comprise the largest portion of the Bureau's efforts, both in time and money. Studies of summer precipitation regimes will continue in South Dakota and Arizona. Winter precipitation regimes will continue to be studied in California, Washington, Montana, Nevada, Utah, Arizona, New Mexico, Colorado, and Wyoming, with equipment and instrument installations continuing in some areas.

Laboratory experiments, while not large in terms of time and money, represent an important part of our program. Programs are underway to study the behavior of artificial nuclei when introduced into the cloud base; to find better ways to detect seeding material in precipitation as an aid in evaluating seeding effectiveness; and to continue the development and refinement of telemetering precipitation gages.

Theoretical and statistical studies will continue to be supported at the South Dakota School of Mines, University of Nevada, Aerometric Research, Inc., Taft College, Fresno State College Foundation, Colorado State University, Naval Ordnance Test Station, U. S. Forest Service, U. S. Weather Bureau, and W. E. Howell Associates. These studies include mathematical modeling of cloud and precipitation processes, evaluation techniques, new seeding agents and devices, and cloud and storm climatology.

Development of technology is a natural outgrowth of the research efforts. The Bureau will continue in FY 67 to develop seeding technology for cap clouds, summer cumulus and winter orographic cloud systems, and emphasis will be exerted to exploit the capabilities of current instrumentation and equipment (radar, for example).

Systems development will become an increasingly important part of the program. During FY 67 the Denver Office staff of the Bureau of Reclamation will continue work in this area, with valuable assistance from contractors on the details of the components. In particular, efforts will be directed towards increasing knowledge of data gathering and processing during FY 67.

BUREAU OF RECLAMATION WEATHER MODIFICATION PROGRAM FOR FY 1970

In FY 70 field experiments will continue to be the area of greatest effort, and it is anticipated that research activities will have expanded to include the entire nation. By FY 70 it is expected that some areas, perhaps one in the East and one in the West, will have pilot plant operational programs. Among the major investigations will be continued studies of the feasibility of redistributing precipitation as part of the total water resources development of the nation. Most of the field experiments of FY 66 will be continued at higher levels of effort. However, a few may be terminated as answers to specific problems are found. It is anticipated that major steps forward will be taken in ground-to-ground and air-to-ground telemetry operations and also in establishing a nationwide weather radar surveillance network to aid in detecting seeding opportunities and evaluating results.

With the availability to the program of major cloud chamber facilities acquired in prior years, it is anticipated that many of the unanswered questions of cloud and precipitation processes can be investigated. Other problems discovered as a result of previous work will continue to receive attention in FY 70. In addition to studies directly related to cloud seeding, indirect influences, such as socio-economic and biological factors, will be examined.

Development of technology will be proceeding at a high pace in view of the expanding program. It is expected that considerable progress will be made toward developing an "operational manual" for several areas of the nation.

Systems development will continue to receive major attention during FY 70. Studies in proper management of research and operational programs will receive increasing support as the program in atmospheric water resources progresses.

NATIONAL SCIENCE FOUNDATION WEATHER MODIFICATION
PROGRAM FOR FY 1967

In FY 1967, efforts will be made to build on the present competence available in universities and other appropriate institutions and to encourage cooperative efforts between smaller groups to pool their talents and provide mutual support in which combined efforts can be made to yield much greater impact. The Hailswath Project in which 22 separate research groups are pooling their efforts toward the common goal of hail suppression research at a specific location is an example of this type of cooperative research.

Cooperative arrangements on a smaller scale between the staffs of different universities to supplement talents are also being encouraged by the National Science Foundation. Typical cooperative ventures are the testing of new nucleating materials developed at Lehigh University by the University of Chicago field project Whitetop, the testing of ultrapure silver iodide produced by the University of Arizona in the calibration facility of the Colorado State University, and the operation of a radar facility at Chadron State College by the research team from the South Dakota School of Mines. The role of the National Science Foundation in bringing together diverse research talents into cooperative research teams is vital in developing the talented manpower resources needed for the future, and will insure that a critical size of effort can be attained to be effective.

Increasing emphasis is being made to supplement the operational "know-how" of the field research or operational project with the technical and theoretical skill of the trained university scientist. The recent grant to the North Dakota State College to assist and evaluate the Bowman-Slope Hail Association efforts on hail suppression is an example where both groups will benefit by their mutual interface.

Wherever possible, commercial operators are being encouraged to incorporate research aspects into their commercially sponsored seeding projects. Recent contracts with Wallace E. Howell Associates to scientifically evaluate the salt seeding of warm clouds over the Virgin Islands and with Atmospherics, Inc. to evaluate the effectiveness of their seeding program in the Kings River drainage basin in California are examples of this effort.

The initiation of interest in weather modification in universities where competence may grow is also a goal of the National Science Foundation program. In FY 1966, efforts were initiated at Chadron State College, in Nebraska, North Dakota State College in North Dakota, and at the University of Washington, in Seattle, to germinate new sources of competence which will produce the talent for the future.

The growing interest in the social, economic, legal, biological and ecological impacts of weather modification created by the recent report of the National Science Foundation Special Commission on Weather Modification is being fostered by the formation of the Task Group on Human Dimensions for Weather Modification at the National Center for Atmospheric Research and by a grant with the University of Missouri to study the socio-economic impact of weather and climate modification. This is a field of research which will receive increasing emphasis by the National Science Foundation in the future.

NATIONAL SCIENCE FOUNDATION WEATHER MODIFICATION PROGRAM
FOR FY 1970

In FY 1970, it is anticipated that many of the small university research groups will find it advantageous to combine their efforts into larger research teams in order to approach the study of the atmosphere in situ rather than in the laboratory. This will require increased capability for mobility in field operations in order to achieve their research goals. This may well be provided by attaching research teams to existing field weather modification operational projects already in existence, or by a pooling of aircraft, vehicle, radar and ground network equipment by a number of university groups.

It is anticipated that there will be a few large-scale facilities funded for the testing of modification schemes. Typical schemes might be the suspension of a spray nozzle over a valley between two mountain peaks to produce cloud-sized droplets into which electrical charges can be introduced in either polarity, contaminants can be introduced, and the drop size spectrum can be adjusted to any reasonable distribution. Under NSF sponsorship, a large aircraft or blimp hanger may also be converted into a fog chamber for testing warm fog dissipation techniques.

Research will still continue in university laboratories on basic problems relevant to understanding atmospheric processes, and "small science" hopefully will continue to be supported along with the efforts of "big science." Emphasis will be increased on the mathematical modeling of the atmospheric processes and on the techniques for simulating modification processes on the computer before testing them in the atmosphere.

Increasing attention will be paid to the problem of making measurements in the atmosphere. NSF will support studies by qualified engineers for the design of standardized instrumentation and calibration techniques which will be made available to the scientific community.

By FY 1970, the approach to the problem of the social, economic, legal, biological and ecological aspects of weather modification should become sufficiently clear so that significant research efforts in these areas can be fostered and expanded. The solution of these problems will be equally difficult as those faced by the physical scientist in weather modification, but models and procedures will evolve which will require major support of field evaluation studies and high-speed computers. These will be approached within the university community and by larger study groups with commensurate resources in manpower and computer capabilities. By FY 1970, it is planned that this effort will approach the million dollar level of support.

In general, by FY 1970 it is visualized that the transition of weather modification from "small science" to "big science" will be well on the way. NSF will continue to provide the major support of the university researcher and his graduate students in the field of basic atmospheric research in weather modification. The matrix figures for NSF in FY 1970 are an estimate of the needs of the non-government scientific community.

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
WEATHER MODIFICATION PROGRAM FOR FY 1967

NASA's program in weather modification in FY 1967 will be primarily a continuation of the effort being supported under contract with the Cornell Aeronautical Laboratories, Inc. on the investigation of warm fog properties and fog modification concepts.

This project to date has emphasized analytical and experimental work on studies of the micro and macroscopic properties of warm fogs, techniques for observing fog parameters, the simulation of fog conditions, the experimental modification of fog, and the formulation of mathematical fog models.

During FY 1967 laboratory investigations of fog dispersal by electrification principles will be continued. Proposed ideas for producing condensation nuclei will be further investigated and laboratory experiments will be conducted to evaluate the concept for preventing dense radiation fog. Nuclei measurements will be continued on a daily basis, and will be correlated with measurements taken on previous years.

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
WEATHER MODIFICATION PROGRAM FOR FY 1970

In FY 1970, it is planned to continue the work at the Cornell Aeronautical Laboratories in warm fog research which will provide the basis for dissipation techniques.

In the conduct of weather modification experiments, an instrumented satellite viewing the area from above will be extremely useful to the analysis of the modification efforts. A manned observer in space would be able to perform this support activity with even greater skill. Thus, observations from space can be very helpful in conducting experiments in weather modification.

Space launch vehicles pour out a tremendous volume of exhaust gases during their active burning stage. In quantity, the gases exceed by several orders of magnitude the quantities normally found in the atmosphere at these levels. This situation must be kept under continuous study in order to insure that future programs for launching space flight vehicles, both in this country and by other countries, will not have a significant effect on the composition and motion of the atmosphere. NASA would be pleased to join a study effort to explore this area further.

NASA's role in aeronautics and particularly in the development of the supersonic transport naturally involves it in the over-all program of severe storm prediction and possible modification and dissipation of severe storms artificially. From this point of view, NASA would encourage the active programs that would lead to an eventual control of storms or other conditions affecting aircraft flight.

FEDERAL AVIATION AGENCY WEATHER MODIFICATION PROGRAM FOR FY 1967

Although the FAA maintains an interest in all aspects of weather modification which may be applied to further increasing the safety of aviation and/or to providing more effective movement of air commerce, the present research and development plans and programs are focused on methods to disperse fog from airports. The program begins with a definition of requirements, obtaining preliminary cost information regarding the economics of a system to modify fog at airports, and determining criteria for the extent of the application of the system.

The heat technique appears most promising for field experimentation. A preliminary economic analysis is scheduled to begin in late FY 1966 or early FY 1967, with studies of test design and system effectiveness criteria being carried out in FY 1967.

FEDERAL AVIATION AGENCY WEATHER MODIFICATION PROGRAM FOR FY 1970

Studies of system effectiveness and test design carried out in FY 1967 will result in the procurement of experimental devices and the testing of these devices to refine and verify the capabilities and limitations of a fog dispersal system. Present plans call for field experimentation to begin in FY 1968, and reaching peak effort in FY 1969 and FY 1970. Following this period of intense field activity, there will be a decrease in research and development activity as the engineering and operational phases of the program become more important and arrangements are made for operational applications to proceed as planned.

FEDERAL COUNCIL FOR SCIENCE AND TECHNOLOGY
INTERDEPARTMENTAL COMMITTEE FOR ATMOSPHERIC SCIENCES
U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20230

June 21, 1966

MEMORANDUM FOR DR. HOMER E. NEWELL

Subject: National Weather Modification Program

At its Sixty-fourth Meeting on June 20, 1966 ICAS agreed to proceed with the development of a National Weather Modification Program along the lines delineated in the report of its Select Panel on Weather Modification of the same date.

You are requested to formulate this program with such assistance as you may request from any or all ICAS members. You are specifically provided the assistance of a qualified weather modification scientist from each of the following agencies: ESSA, Bureau of Reclamation, NSF, Department of Agriculture.

You are requested to provide at least these three elements in the Program:

1. Analysis of a major program of weather modification for the needed expansion of activity toward the goals of fog and cloud dissipation, precipitation modification, etc. as delineated in the Select Panel Report and toward such other goals as you may want to specify.

2. Analysis of the techniques to be used and such supporting activities as computers, mobile facilities, etc.

3. Definition of what agencies should carry out the activities recommended, first as to responsibility for the program (budget support), and second as to actually conducting the activity. If you are unable to recommend specific allocation of responsibility your recommendations for the solution of the problem should be included.

I believe the following documents provide substantive background information that would assist you. Copies are enclosed.

ICAS Memo to Dr. Hornig dated March 11, 1966
S. 2916 as amended May 12, 1966
BOB Circular A-62 dated November 13, 1963
The Federal Plan for Meteorological Services and Supporting Research, FY 1967

J. Herbert Hollomon
Chairman

NASA PANEL TO STUDY WEATHER MODIFICATION ACTIVITIES

MEMBERSHIP

CHRONOLOGY OF MEETINGS

COMPILATION OF SUPPORTING
MATERIAL USED BY THE PANEL

APPENDIX V

PANEL TO STUDY WEATHER MODIFICATION ACTIVITIES

Membership

Homer E. Newell, Associate Administrator for Space Science and Applications, NASA Headquarters, Chairman

J Allen Crocker, Deputy Director, Program Review and Resources Management, OSSA, NASA Headquarters

Leonard Jaffe, Director of Applications, OSSA, NASA Headquarters

Ernest A. Neil, Senior Staff Assistant, Project Directorate, Goddard Space Flight Center (GSFC)

William Nordberg, Assistant Chief, Laboratory for Atmospheric and Biological Sciences, GSFC

Nelson W. Spencer, Chief, Laboratory for Atmospheric and Biological Sciences, GSFC

William C. Spreen, Meteorology and Soundings Program Chief, Space Applications Programs, OSSA, NASA Headquarters

Morris Tepper, Director of Meteorology, Space Applications Programs, OSSA, NASA Headquarters

PANEL TO STUDY WEATHER MODIFICATION ACTIVITIES
Chaired by Homer E. Newell
Associate Administrator for Space Science & Applications
NASA Headquarters

Chronology of Meetings

21 June 1966, NASA Headquarters
Receipt of Hollomon memo dated 21 June 1966 giving assignment to Homer E. Newell, and the organization of a Panel to assist Newell

27,28 June 1966, NASA Hqs
Panel briefings by Department of Interior, Department of Commerce, Department of Agriculture, National Science Foundation, Bureau of the Budget, and Office of Science and Technology

28 June 1966, NASA Hqs
Executive Panel session

1 July 1966, NASA Hqs
Panel briefing by Dr. Earl Droessler

26 July 1966, NASA Hqs
Panel staff meeting

15-18,25 August 1966, GSFC
Panel sessions with Agriculture, Interior, ESSA, NSF

6 September 1966, NASA Hqs
Panel meeting

7 September 1966, GSFC
Ad hoc session

9 September 1966, OST
Report to Hornig, OST

21,26 September 1966, NASA Hqs
Ad hoc sessions

28 September 1966, NASA Hqs
Panel meeting

Panel to Study Weather Modification Activities
Chaired by H. E. Newell

Supporting Material Used by the Panel

OVERALL

1. Memorandum for Dr. Homer E. Newell from J. Herbert Hollomon, Chairman, ICAS, Subject: National Weather Modification Program, dated June 21, 1966

2. Report prepared by the ICAS Select Panel on Weather Modification PRESENT AND FUTURE PLANS OF FEDERAL AGENCIES IN WEATHER-CLIMATE MODIFICATION, dated June 20, 1966

3. Final Report of the Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences, National Academy of Sciences-National Research Council WEATHER AND CLIMATE MODIFICATION, PROBLEMS AND PROSPECTS, Volume I-SUMMARY AND RECOMMENDATIONS, Volume II-RESEARCH AND DEVELOPMENT, Publication No. 1350, 1966

4. U.S. Senate Bill (S.2916 - 89th Congress) to be proposed by Magnuson, to provide for a weather modification program to be carried out by the Secretary of Commerce, May 12, 1966, Referred to the Committee on Commerce

DEPARTMENT OF AGRICULTURE

U.S. Department of Agriculture presentation to Newell on June 28, 1966

5. Weather Modification Program Analysis

6. Summary of Weather Modification Research Program

7. Statement of T. C. Byerly, Administrator, Cooperative State Research Service, United States Department of Agriculture, on S.2916 before the Committee on Commerce, U.S. Senate, on March 7, 1966

8. U. S. Dept. of Agriculture Forest Service A SUMMARY OF PROJECT SKYFIRE dated September 1, 1966, transmitted by letter to Crocker from J. S. Barrows, Director, Forest Fire Research, dated September 6, 1966

DEPARTMENT OF INTERIOR

9. WATER RESOURCES IN THE SKY, Stewart L. Udall, Bulletin American Meteorological Society, Vol 47, No. 4, April 1966, pg 275-278 (Speech presented at the 46th Annual Meeting of the AMS, Evening Banquet, 26 January 1966, Denver, Colorado)

10. Presentation to ICAS on May 13, 1966, PLANS FOR THE DEPARTMENT OF THE INTERIOR'S ATMOSPHERIC WATER RESOURCES PROGRAM

11. Dept. of Interior, Manpower Requirements and Cost Estimates (from Sept 1966 Plan Report)

12. Estimates of Facilities and Major Equipment and Services in support of the Dept. of Interior's Program received 16 August 1966

DEPARTMENT OF COMMERCE

13. Draft SUMMARY OF INFORMATION RELATED TO MR. CROCKER FROM FERGUSON HALL dated August 26, 1966, regarding ESSA manpower requirements related to Weather Modification

ESSA Weather Modification Program Review for Newell on June 28, 1966

14. Outline of A PROPOSED FIVE-YEAR PLAN IN WEATHER MODIFICATION, U. S. Department of Commerce, Environmental Science Services Administration, April 1966; with ATTACHMENT: FISCAL AND MANPOWER REQUIREMENTS with Addendum FISCAL AND MANPOWER DATA FOR 1966 AND 1967

15. ESSA Weather Modification Program Schedule, Fiscal Years 1967-1970

16. Presentation by the Deputy Federal Coordinator for Meteorological Services & Supporting Research (Moore)

17. THE FEDERAL PLAN FOR METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH, FISCAL YEAR 1967, U.S. Department of Commerce, Environmental Science Services Administration, Office of Federal Coordinator for Meteorological Services and Supporting Research

18. Summary papers of ESSA presentations at the Weather Modification Review meeting, GSFC, August 17, 1966

NATIONAL SCIENCE FOUNDATION

19. Report of the Special Commission on Weather Modification, National Science Foundation, WEATHER AND CLIMATE MODIFICATION, Publication No. NSF 66-3, transmitted to NSF December 20, 1965

20. Report to the Special Commission on Weather Modification, National Science Foundation, WEATHER MODIFICATION LAW, CONTROLS, OPERATIONS, Publication No. NSF 66-7 (no date)

21. National Science Foundation Act of 1950 (PL 507-81st Congress) As Amended Through August 15, 1963, and as Modified by Reorganization Plan No. 2 of 1962, Effective June 8, 1962

22. First Annual Report, 1959, National Science Foundation, WEATHER MODIFICATION, NSF 60-24

23. Second Annual Report, 1960, National Science Foundation, WEATHER MODIFICATION, NSF 61-30

24. Third Annual Report, 1961, National Science Foundation, WEATHER MODIFICATION, NSF 62-27

25. Fourth Annual Report. 1962, National Science Foundation, WEATHER MODIFICATION, NSF 63-29

26. Fifth Annual Report, 1963, National Science Foundation, WEATHER MODIFICATION, NSF 64-19

27. Sixth Annual Report, 1964, National Science Foundation, WEATHER MODIFICATION, NSF 65-9

28. Seventh Annual Report, 1965, National Science Foundation, WEATHER MODIFICATION, NSF 66-4

29. Proceedings of THE SEVENTH INTERAGENCY CONFERENCE ON WEATHER MODIFICATION, September 30 - October 1, 1965, Big Meadows Lodge, Skyline Drive, Shenandoah National Park, Virginia

30. Report of the FIRST NATIONAL SYMPOSIUM ON HAIL SUPPRESSION. Dillon, Colorado, October 14-15, 1965

31. HUMAN DIMENSIONS OF WEATHER MODIFICATION, W. R. Derrick Sewell (Ed), U of Chicago, Dept of Geography, Res Paper No. 105, 1966 (Papers prepared in connection with a Symposium on the Economic and Social Aspects of Weather Modification which was held at NCAR in Boulder, Colorado, from July 1-3, 1965, under NSF sponsorship)

32. PRESENT PROGRAM AND FUTURE PLANS OF THE NATIONAL SCIENCE FOUNDATION IN WEATHER AND CLIMATE MODIFICATION RESEARCH, Revised June 27, 1966

33. Letter to Dr. Newell from P. H. Wyckoff, dated June 28, 1966, regarding the NSF Weather Modification Program with enclosure, "Critique by Presenter"

BUDGET RECOMMENDATIONS AND TRENDS

for a

National Weather Modification Program

APPENDIX VI

Fig. 1 BUDGET RECOMMENDATIONS FOR A NATIONAL WEATHER MODIFICATION PROGRAM
APP. VI OF A REPORT TO ICAS BY HOMER E. NEWELL, 1 OCTOBER 1966

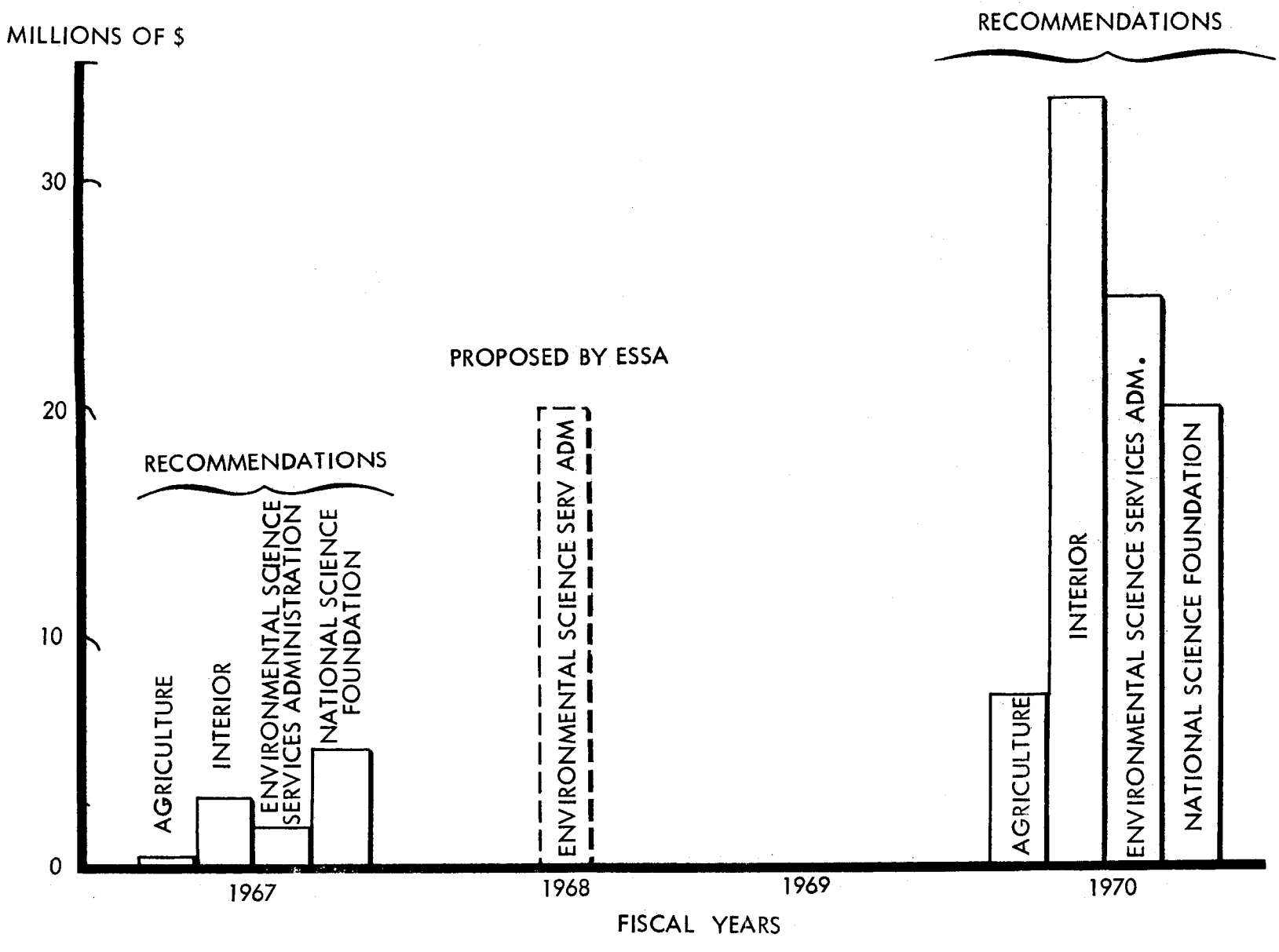
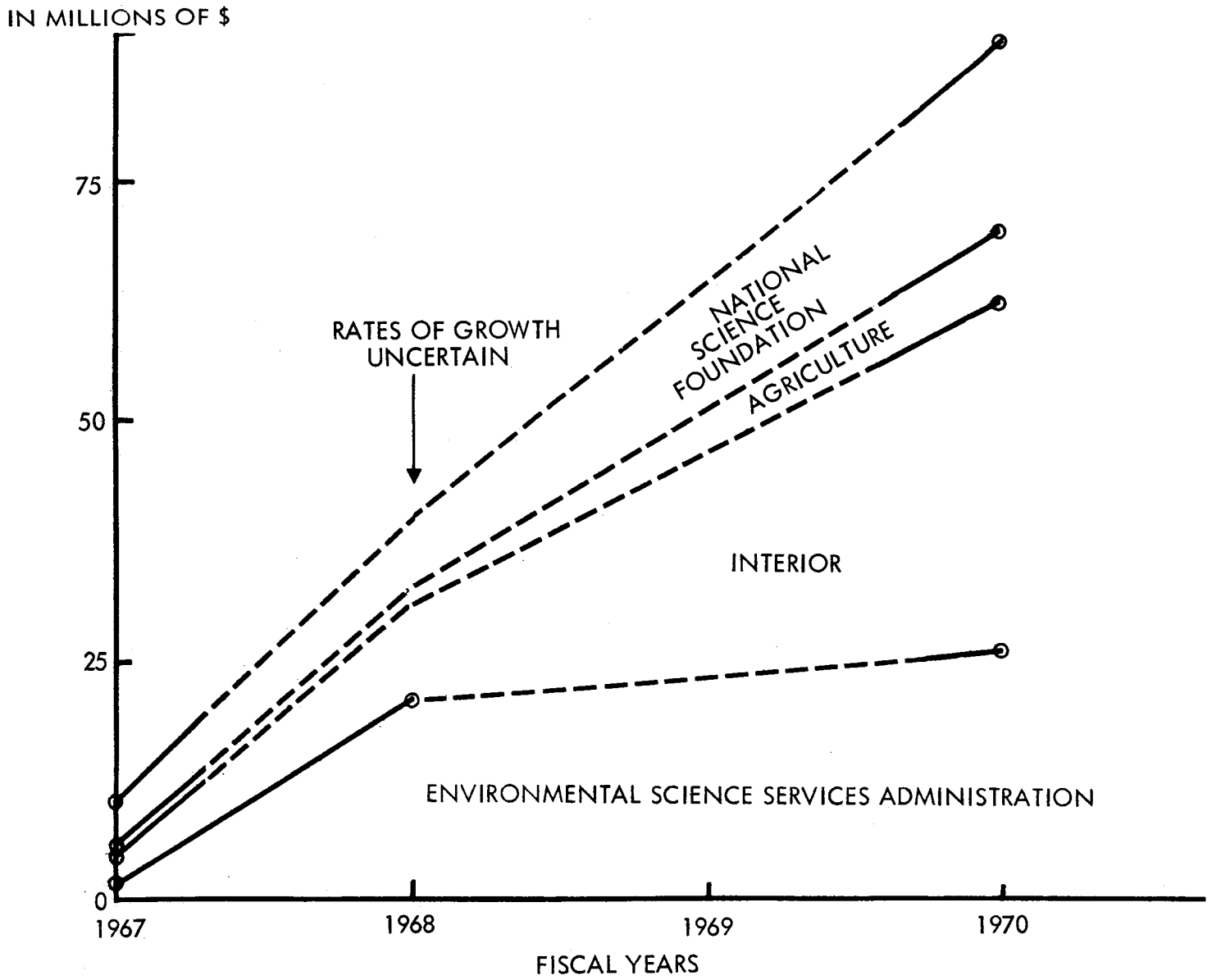


FIG. 2 BUDGET TRENDS IN WEATHER MODIFICATION SUGGESTED BY BAR GRAPH OF FIG. 1
APP. VI OF A REPORT TO ICAS BY HOMER E. NEWELL, 1 OCTOBER 1966



* U.S. GOVERNMENT PRINTING OFFICE: 1967—251-026/100